PB85-205516

Sources of Ethylene Oxide Emissions

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Apr 85

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-450/3-85-014		PB85 205516/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Sources of Ethylene Oxide Emissions	April 1985
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
David W. Markwordt	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning Standards U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Director for Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The objective of this report is to present the results of a preliminary source assessment study conducted for ethylene oxide in which emission, cost, and dispersion data were developed that will aid in evaluating the need for further regulatory development for ethylene oxide.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Pollution Control Ethylene Oxide	Air Pollution Control	13/b

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	80
	20. SECURITY CLASS *(This page)*	22 PRICE
	Unclassified	

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

PB85-205516

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-85-014
April 1985

Air

EPA

Sources of Ethylene Oxide Emissions

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

EPA-450/3-85-014

Sources of Ethylene Oxide Emissions

David W. Markwordt
Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

April 1985

i.a.

This report has been reviewed by the Emission Standards and Engineering Division of the Office of Air Quality Planning and Standards, EPA, and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use. Copies of this report are available through the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, N.C. 27711, or for a fee from the National Technical Information Services, 5285 Port Royal Road, Springfield, Virginia 22161.

EXECUTIVE SUMMARY

The objective of this report is to present the results of a preliminary source assessment study conducted for ethylene oxide (EO) in which data were developed that will aid in evaluating the need for further regulatory development for EO.

The EO source assessment was focused primarily on air emissions of EO. Processes which could potentially produce air emissions were identified and the levels of total EO generated were quantified. The EO emitted to air was estimated for individual sources from EO production sites (including captive use), ethoxylation sites, and major sterilizer/fumigator facilities. Emission categories included leaking equipment, cooling towers, vents, storage and loading operations, and effluent treatment facilities. Data were obtained from formal information requests to operating companies.

National emissions of EO are estimated at approximately 5,000 megagrams per year. Production/captive use, ethoxylation, medical facilities, and sterilization/ fumigation sites account for 31, 4, 8, and 57 percent of total emissions, respectively (see Table 1). Currently, 15 plants produce approximately 2.5 million megagrams of EO annually. Approximately, 80-90 percent of EO production is captively used on site. The bulk of emissions from producer and ethoxylator sites are from equipment leaks. Less than 0.1 percent of EO production is used in sterilizer/fumigator process, but nearly all of the uncontrolled EO is emitted to the atmosphere.

Control technologies currently used to reduce air emissions of EO were identified and evaluated to estimate what level of control exists at EO sources. The technologies currently applied, along with other potentially

feasible technologies, were assessed to define what constituted effective control for EO emissions from the various sources. The controls assessment included an examination of control device applicability and effectiveness and control device cost.

Application of available control techniques for all EO emission sources (excluding medical facilities) could reduce emissions by approximatley 87 percent. The control costs per megagram of EO emissions range from 460 to 2,500 depending on the emission source and applied technique.

The decision to initiate regulatory development will depend to some extent on the estimated health effects attributed to exposure to ambient levels of EO. Emission parameters developed for EO dispersion modeling are summarized in Appendix B.

Table 1. NATIONAL EMISSIONS - ETHYLENE OXIDE (Mg/yr)

Source	Baseline Emissions	% Total	Potential Controlled Emissions
A. Production/Captive Use	1,540	31	900-500
1. Equipment Leaks	1,200		700-300
2. Cooling Towers	190		50
3. Vents	100		100
4. Storage and Loading	40		40
5. Effluents	10		10
B. Ethoxylation	200	4	85-50
C. Medical Facilities	400	8	400
D. Sterilization/Fumigation	2,800	57	30
	4,940	100	1,420-980

Table of Contents

Section		Page
1	INTRODUCTION	1-1
2	INDUSTRY PROFILE	2-1
	2.1 Production	2-1
	2.2 Captive Feed Use	2-11
	2.3 Ethoxylation	2-18
	2.4 Sterilization/Fumigation	2-19
3	NATIONAL EMISSIONS	3-1
	3.1 Production Facilities	
	3.1.1 Equipment Leaks	3-5
	3.1.2 Cooling Towers	3-5
	3.1.3 Vents	3-9
	3.1.4 Storage & Loading	3-12
	3.2 Ethoxylation	3-13
	3.3 Sterilization/Fumigation	3-13
4	CONTROL TECHNIQUES	4-1
	4.1 Equipment Leaks	4-1
	4.2 Cooling Towers	4-4
	4.3 Vents	4-5
	4.4 Sterilization/Fumigation	4-5
5	CONTROL TECHNIQUES COSTS	5-1
	5.1 Equipment Leaks	5-1
	5.2 Sterilization/Fumigation	5-1
	References	6-1

Appendices

A - Equipment Leak Control Costs for Ethylene Oxide Model Plants

B - Dispersion Modeling Parameters Results

LIST OF TABLES

Table		Page
1-1	Emission Control Levels	1-4
2-1	Ethylene Oxide Facilities	2-2
2-2	Ethylene Oxide Derivatives	2-3
2-3	Ethylene Oxide (EO) Production Sites Capacity and Captive Uses	2-4
3-1	National Emissions - Ethylene Oxide	3-3
3-2	Average Facility Emissions	3-4
3-3	Model Plant Components for (EO) PSroduction Facilities	3-6
3-4	Ethylene Oxide Equipment Leak Emissions Ethylene Oxide Production: Air - Oxidation	3-7
3-5	Ethylene Oxide Equipment Leak Emissions Ethylene Oxide Production: Oxygen - Oxidation	3-8
3-6	Control Techniques & Emission Rates Air Oxidation	3-10
3-7	Control Techniques & Emission Rates Oxygen Oxidation	3-11
4-1	Equipment Leaks - Control Techniques	4-2
4-2	Control Efficiencies: CTG & NSPS Equipment Components	4-3
5-1	Preliminary Control Efficiency and Cost Effectiveness Ethylene Oxide Emission Sources	5-2
5-2	Equipment Leak Control Costs Ethylene Oxide Production	5-3
5-3a	Equipment Leaks Emissions and Emission Reduction Estimates Ethylene Oxide Production: Oxygen - Oxidation	5-4
5-3b	Equipment Leaks Emissions and Emission Reduction Estimates Ethylene Oxide Production: Air - Oxidation	5-5
5-4	Equipment Leak Control Costs: Ethoxylation	5-6
5-5	Cost Effectiveness - DEOXX™ System	5-7

LIST OF FIGURES

Figure		Page
2-1	Basic Operations That May Be Used in Production of Ethylene Oxide by Air Oxidation	2-7
2-2	Basic Operations That May Be Used in Production of Ethylene Oxide by Oxygen Oxidation	2-10
2-3	Basic Operations That May Be Used in The Production of Ethylene Glycol, Diethylene Glycol and Triethylene Glycol by Conventional Noncatalyzed Hydration of Ethylene Oxide	2-13
2-4	Basic Operations That May Be Used in Production of Glycol Ethers from Ethylene Oxide	2-15
2-5	Basic Operations That May Be Used in Production of Ethanolamines from Ethylene Oxide	2-17

1. INTRODUCTION

1.1 OVERVIEW

This report provides preliminary information on sources of air emissions of ethylene oxide to assist EPA in regulatory decision-making. Potentially significant sources are identified and described, including ethylene oxide production, its captive end-use in ethylene glycol, glycol ether, and ethanolamine production, linear alcohol ethoxylate production, and sterilization/fumigation processes. Source descriptions include general information on each industry and production process, as well as emission estimates, and control technology.

This report also presents emission estimates of EO and control costs for each emission source. Emission parameters were developed to model ambient dispersion concentrations of EO; these parameters are summarized in Appendix B. Emissions were estimated for two control levels: Level 1 represents the baseline level of emission control which would be expected without further regulatory activity, and Level 2 consists of estimated emission control for each emission source beyond baseline levels.

The EO emissions, control data, and costs of control in this report are based on information obtained from formal information requests to operating companies, existing EPA reports and other reports published on the EO manufacturing industry, and from telephone contacts with control equipment vendors. Emission estimates are based on emission data provided by industry and emission factors developed by EPA.

1.2 SOURCE ASSESSMENT METHODOLOGY

This section describes the general methodology used for the source assessment for the EO production, EO captive-feed uses, ethoxylate production, and sterilization/fumigation processes. These areas are addressed below, followed by a brief discussion of the uncertainties involved in emission and cost estimates.

1.2.1 Ethylene Oxide Production/Capitive-Feed Uses

Detailed emission data and corresponding process parameters from each EO oxide production site were provided to the EPA from each operator. EO flow rates (Kg EO/10^3 Kg EO capacity), both inlet and outlet to control devices, were developed for each vent source based on plant data. This information provides control efficiencies, a means of comparing the relative magnitude of each emission source, and the basis for emission rates for dispersion analysis.

The cost of equipment leak control assumed the new source performance standard level of control and cost assumptions; costs are in October 1983 dollars and were estimated on a model plant basis consistent with the emission estimates. Detailed costs are provided in Appendix A.

1.2.2 Ethoxylate Production

Data from only one plant forms the basis for emission estimates for ethoxylation production. It was assumed that the major source of emissions is equipment leaks. The model plant for ethoxylate producer facilities was based on comparison of equipment counts from the one ethoxylate plant and the EO production sites. For emission estimates it was assumed that

ethoxylate producers have about 10 percent of the components of EO production sites (based on data from one facility); the estimate probably overstates emissions from these facilities. Data are needed for a more accurate estimate.

Costs were calculated by averaging the equipment leak control costs for oxygen and air oxidation plant sites and multiplying by 10 percent; costs are in October 1983 dollars.

1.2.3 Sterilization/Fumigation Processes

It was assumed that the typical sterilization and fumigation facility emits all the EO used in the process to the atmosphere. Emission estimates were then based on national estimates of the EO consumed in these processes.

The DEOXX™ system manufactured by Chemrox Inc. is the control technique considered for sterilization/fumigation processes. Information including control efficiency and costs were provided by the vendor; control costs are based on one industrial application.

1.3 NATIONAL EMISSIONS

National emissions of EO are estimated at approximately 5,000 megagrams per year (see Table 1-1). Production/captive use, ethoxylation, medical facilities, and sterilization/fumigation sites account for 31, 4, 8, and 57 percent of the total emissions, respectively. Emissions associated with growth in the industry were not estimated.

1.3.1 Production/Captive Use

Equipment leaks contribute approximately 75 percent of EO emissions at production/captive use sites. Control techniques are summarized in this document which may reduce these emissions by 42 to 75 percent (see Table 1-1).

Cooling towers contribute approximately 13 percent of emissions and may be reduced by approximately 80 percent with appropriate control techniques.

Vents, storage and loading operations, and effluent treatment facilities together contribute approximately 10 percent of total production/captive use site emissions. These sources appear to be well-controlled; additional control may not be necessary.

1.3.2 Ethoxylation

Emissions from equipment leaks may be reduced by 42 to 75 percent, depending on the degree of control implemented.

1.3.3 Sterilization/Fumigation

Add-on control devices may reduce emissions by as much as 99+ percent.

Table 1-1. EMISSION CONTROL LEVELS

Source	Emission Impacts		
	Baseline (Mg/yr)	Controlled (Mg//yr)	Reduction (%)
A. Production/Captive Use	1,540	900 - 500	42 - 68
1. Equipment Leaks	1,200	700 - 300	42 - 75
2. Cooling Towers	190	40	80
3. Vents	100	100	0
4. Storage and Loading	40	40	0
5. Effluents	10	10	0
B. Ethoxylation	200	85 - 50	58 - 75
C. Sterilization/Fumigation*	2,800	32	99
	4,540	1,020 - 580	78 - 87

*(Excluding medical facilities)

2. INDUSTRY PROFILE

Twelve companies at 15 locations produce ethylene oxide in the United States; 2.5 million megagrams were produced in 1983. Most ethylene oxide is used at the production site to produce ethylene glycols, glycol ethers, and ethanolamines. Nameplate ethylene oxide captive feed requirements are 80 percent of nameplate ethylene oxide production capacity. Captive feed levels are approximately 90 percent of actual ethylene oxide production rates.

Of the ethylene oxide that is not used by producers (< 12 percent production), approximately 99.9 percent is sold to detergent manufacturers where ethylene oxide is ethoxylated for use in making surfactants. Less than .1 percent of ethylene oxide is used in the sterilizer and fumigator industries.

The number of facilities involved in production and consumption of ethylene oxide is summarized in Table 1. A complete breakdown of ethylene oxide derivations is provided in Table 2.[1]

2.1 Production. Name plate capacity for the 15 production sites totalled 3.3 million megagrams (7.3×10^9 lbs.) in 1983. Production site locations, capacities, and captive uses are summarized in Table 3.[2,3]

2.1.1. Process Description.[4] Ethylene oxide is produced by the direct, vapor phase oxidation of ethylene over a silver catalyst at 10 to 30 atm. pressure and 200 to 300°C. The main reaction is as follows:

$$CH_2 = CH_2 + 1/2\ O_2 \xrightarrow[\text{Ag Cat}]{} CH_2 - CH_2 + 106.7\ \text{kJoules}^* \quad (1)$$

(ethylene oxide)

*Calculated at 250°C, 15 atm.

Table 2-1

Ethylene Oxide Facilities

Facility	Number of Facilities	End-Use (Mg/year)	National Emissions (Mg)
Producer (Captive Use)	15	2.5×10^6	1.6×10^3
Sterilizers/Fumigators	100-450	2.8×10^3	2.8×10^3
Ethoxylators	50	0.4×10^6	0.2×10^3

Carbon dioxide and water are the only significant by-products formed, according to the following reactions:

$$CH_2 = CH_2 + 3\ O_2 \longrightarrow 2\ CO_2 + 2\ H_2O + 1323\ kJ^* \quad (2)$$

$$CH_2\ CH_2 + 5/2\ O_2 \longrightarrow 2CO_2 + 2H_2O \quad (3)$$

(ethylene oxide)

The main reaction also produces small amounts of acetaldehyde (less than 0.1 percent of EO product) and trace amounts of formaldehyde.

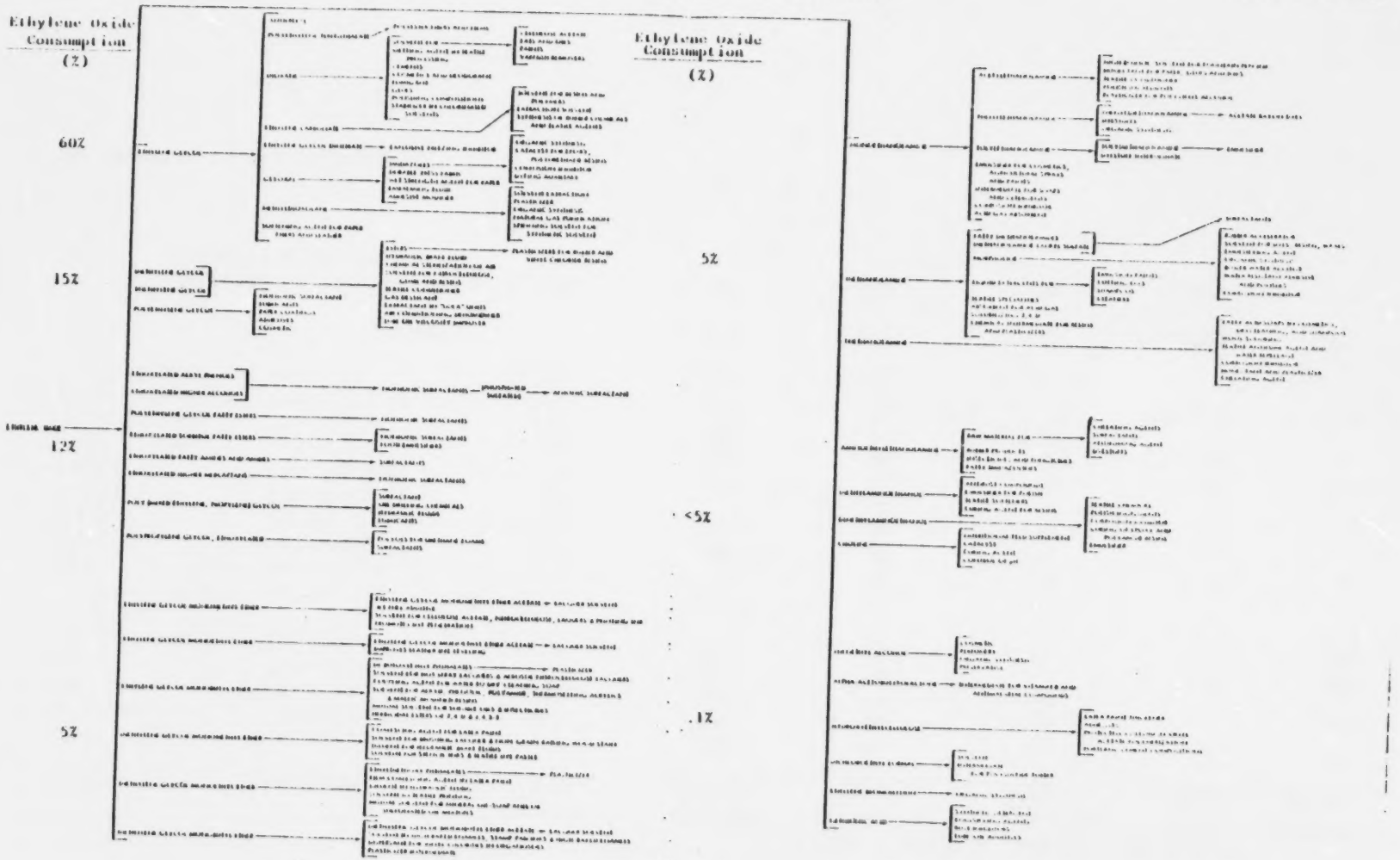
Both the ethylene reaction rate and purge losses increase with higher concentrations of ethylene and oxygen. Thus, depending on the process and the oxidant, the ethylene concentration in the reactor inlet will vary between 5 and 40 volumn percent. The inlet oxygen concentrations will be controlled between 5 and 9 volume percent to stay out of the explosive range. Normally, air-based reactors operate at the low end of this concentration range while oxygen-based reactors operate at the high end.

By controlling the appropriate operating conditions, modern reaction systems are able to maintain selectivities (mols ethylene oxide formed per

*Calculated at 250°C, 15 atm.

TABLE 2-2.

Ethylene Oxide Derivatives



Reproduced from best available copy.

TABLE 2-3. ETHYLENE OXIDE (EO) PRODUCTION SITES*
CAPACITY AND CAPTIVE USES

Producer	Location	1982 Production Capacity (MM lbs/yr)					
		Ethylene Oxide	Ethylene Glycol	Diethylene Glycol	Triethylene Glycol	Glycol Ethers	Ethanol-amines
BASF	Geismar, LA	480	325	35	-	-	-
Celanese	Clear Lake, TX	425	400	50	10	-	-
Dow	Freeport, TX	300	300	30	50	-	-
Dow	Plaquemine, LA	450	450	50	-	120	125
ICI Americas	Bayport, TX	500	450	50	-	-	25
Northern Petrochemical	Morris, IL	230	350	35	-	-	-
Olin	Bradenburg, KY	110	50	5	5	70	30
PPG	Beaumont, TX	170	200	20	2	13	-
Shell	Geismar, LA	700	350	30	10	50	-
Sun Olin	Claymont, DE	110	-	-	-	-	-
Texaco	Port Noches, TX	700	500	50	20	40	240
Texas Eastman	Longview, TX	195	180	20	2	230	-
Union Carbide	Ponce, P.R.	650	840	75	75		-
Union Carbide	Seadrift, TX	920	850	75	-	490	230
Union Carbide	Taft, LA	1,300	1,350	120	-		-
	TOTALS	7,200	6,600	645	174	1,013	650
	NAMEPLATE EO CAPTIVE FEED CAPACITY REQUIREMENTS	6,900	4,700	540	150	1,070	470

*As reported in the literature.

100 mols ethylene reacted) between 65 and 75 percent for air-based processes and between 70 and 80 percent for oxygen-based processes. The selectivity range for the air process is lower because of the purge reactors which, of necessity, operate with low ethylene concentrations and at high conversions per pass. These high reaction efficiencies are achieved by operating with low ethylene conversions per pass and adding controlled, trace amounts of chlorinated inhibitors to moderate the reaction.

Since the reactor exit gas contains substantial amounts of unconverted ethylene, it must be recycled back to the reactor to achieve a high overall ethylene conversion in both the air and oxygen-based processes. The exit gas to be recycled is first scrubbed using water to absorb the ethylene oxide, which if not removed from the feed, would inhibit the reaction and also result in excessive oxidation losses (to CO_2 and H_2O).

In the air-based process, a considerable amount of nitrogen is introduced in the air feed to the reaction. Accordingly, a large portion of the scrubbed reactor exit gas must be withdrawn to remove this nitrogen. This purge stream is usually mixed with additional air to increase the oxygen concentration and then passed through a secondary (or purge) reactor, similar to but smaller than the first (or main) reactor to convert most of the contained ethylene. In large plants, a third stage of reaction is used to achieve an overall ehtylene conversion well in excess of 95 percent of the total feed.

In the oxygen-based process, since high-purity oxygen is used, much less inert gas is introduced into the reaction system. As a result, only a limited purging is required and the unconverted ethylene can be more completely recycled. To avoid a build-up of by-product carbon dioxide, a portion of the recycled gas is first sent to a carbon dioxide removal system where CO_2 is

preferentially absorbed and vented with a minimum loss of ethylene. The reduced purge permits the O_2-based reactor to operate at a high ethylene concentration without excessive vent losses and allows the use of different diluent gases.

In the air based process, nitrogen must be used as the diluent for the oxygen and ethylene since any other diluent would be vented together with the nitrogen. The oxygen process can, however, use other diluents (such as methane) which allow the safe use of high concentrations of both ethylene and oxygen, thus leading to increased productivity at high selectivities.

Both the air- and oxygen-based processes use shell and tube reactors with the catalyst contained in the tubes and a cooling medium in the shell. Boiling water is now the preferred shell-side coolant for new reactors because of improved safety over non-boiling heat transfer oils and boiling kerosene, which were used in the past.

2.1.2 Air Oxidation.[5] Figure 2-1 is a typical flow diagram for a continuous air-oxidation process. Ethylene and air (S1 and S2) are added to a recycle ethylene stream (S3), which feeds one or more primary reactors operated in parallel. The air:ethylene feed ratio, usually about 10:1, is varied with the recycle gas to ensure an optimum oxygen:ethylene ratio. Oxidation takes place over a silver catalyst packed in tubes. The reactor is surrounded by a heat transfer fluid to control the temperature; the reaction temperature and pressure are maintained at 220 to 280°C and 1 to 3 MPa (42>° to 536°F; 10-30 atm). The unreacted ethylene is separated from the reaction products and recycled through the reactor until consumed.

The effluent from the primary reactor (S4) is cooled by the recycle stream from the main absorber (S3) to about 38°C in a shell-and-tube heat

*S1 = Steam 1

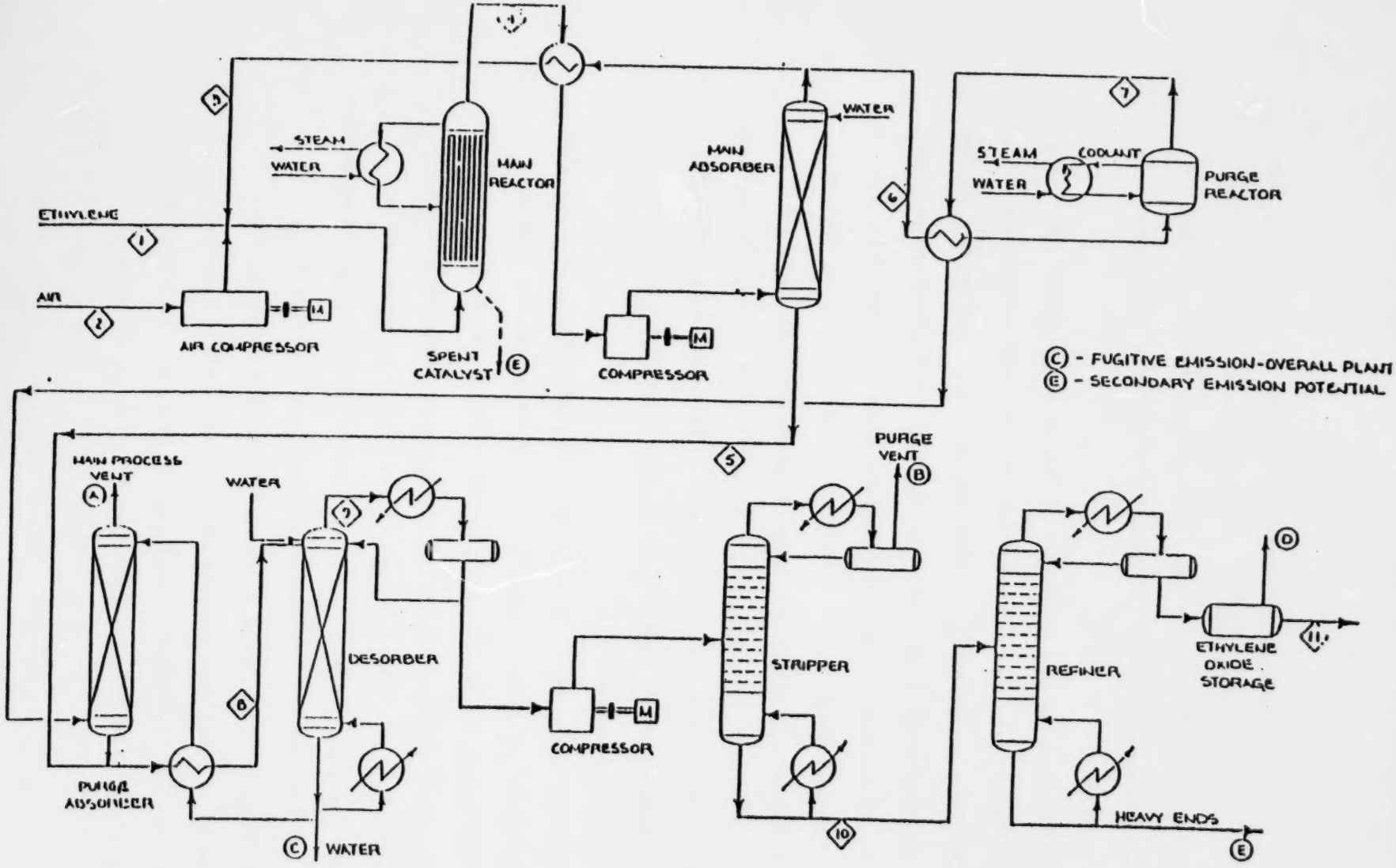


Figure 2-1. Production of Ethylene Oxide by Continuous Air-Oxidation Process[5]

exchanger; it is then compressed before entering the main absorber. The effluent passes up the main absorber countercurrent to cold water, in which the EO, along with some of the carbon dioxide from the stream, dissolves. The water solution is removed from the base of the main absorber (S5).

Unabsorbed gas passing overhead from the main absorber is split into two unequal portions. The larger portion (S3) recycles through the reactor effluent cooler and joins fresh reactor feed. The smaller portion (S6) is passed through a heat exchanger to raise its temperature and then enters the purge reactor (secondary ethylene conversion reactor). The effluent from the purge reactor (S7) is cooled by the incoming feed to the purge reactor and enters the purge absorber, where ethylene oxide is removed from the stream with water, as in the main absorber. The overhead gas (VA) is vented from the purge absorber. There can be more than one stage of purge reaction, depending on the economics of the value of ethylene recovered versus cost.

The dilute water solutions containing ethylene oxide, carbon dioxide, and other volatile organic chemicals from both absorbers are combined (S8). The mixture is fed to the top of the desorber, where the crude ethylene oxide (S9) is distilled off the top and compressed for further refining. A stripper removes carbon dioxide and inert gases overhead (VB), and the EO, stripped of carbon dioxide (S10), is fed to the midsection of the refiner, where it is distilled overhead to 99.5 mole % EO. The product (S11) is stored under a nitrogen atmosphere. The secondary reaction of ethylene that produces CO_2 represents not only a loss of ethylene but also a release of more than 13 times as much energy as the primary product reaction, i.e., 50.4 vs 3.7 MJ/kg of ethylene.

2.1.3 Oxygen Oxidation.[6] Figure 2-2 is a typical flow diagram for a continuous oxygen-oxidation process. A higher concentration of ethylene allows more ethylene to be converted per pass without exceeding the 30% ethylene conversion favorable for optimum selectivity for EO formation. The oxygen-oxidation process also allows recirculation of the unabsorbed gas through the reactor to achieve a higher conversion. The higher ethylene conversion eliminates the need for the purge-reactor absorber system required by the air-oxidation process.

As shown by the oxygen-oxidation flow diagram, Fig. 2-2, the purge reactor and purge absorber of the air-oxidation process are replaced by a CO_2 absorber and reactivator. EO, along with some CO_2, is dissolved in the water stream leaving the base of the main absorber (S6) and is fed to the top of the desorber. The desorption, stripping, and refining steps are similar to those of the aqueous effluent from the main absorber of the air-oxidation process (S8, Fig. 2-1).

Part of the unabsorbed gas overhead from the main absorber of the oxygen-oxidation process (S7) passes through a CO_2 absorber before being recycled back to the reactor feed (S8). Carbon dioxide must be removed to maintain favorable catalyst activity and favorable conversion to EO. The CO_2 absorbent, usually potassium carbonate (S9), is heated by the bottoms from the reactivator and then fed to the top of the reactivator, where it is stripped of carbon dioxide and recycled to the CO_2 absorber.

Small amounts of gaseous impurities in the feed, such as argon, must be removed since they will accumulate in the closed system. Some of the recycle gas stream is purged through the argon purge vent (VB). This emission flow rate is automatically regulated by the argon concentration.

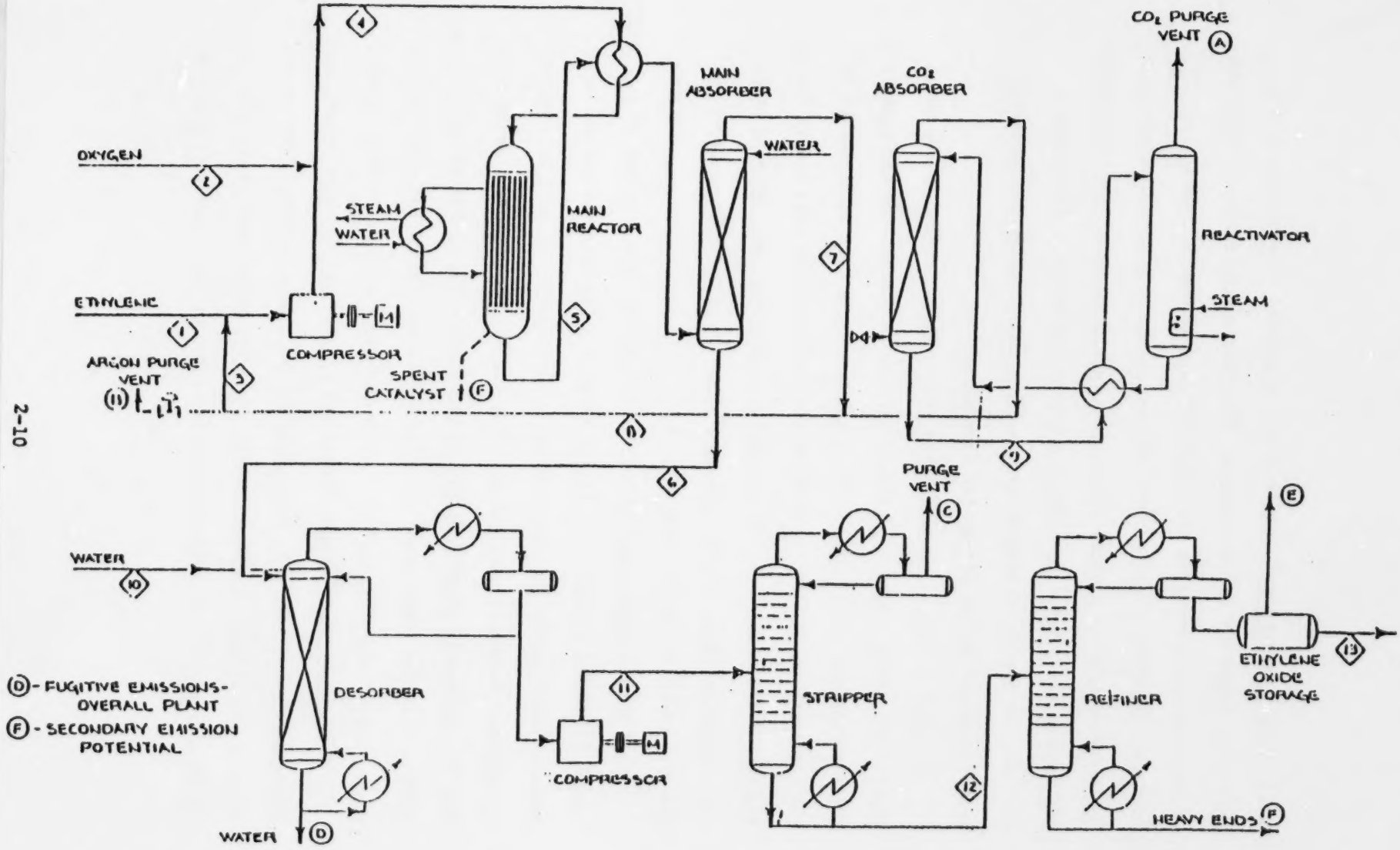
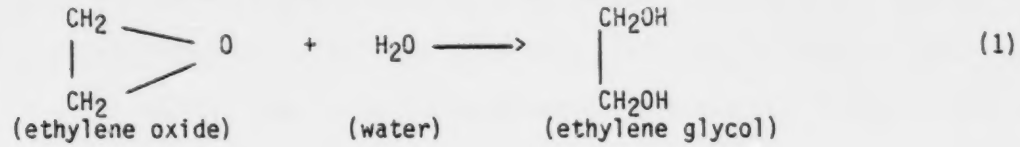


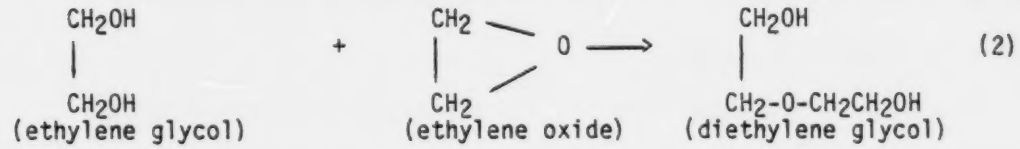
Figure 2-2. Production of Ethylene Oxide by Continuous Oxygen-Oxidation Process[5]

2.2 Captive Feed Use[5,6,7]

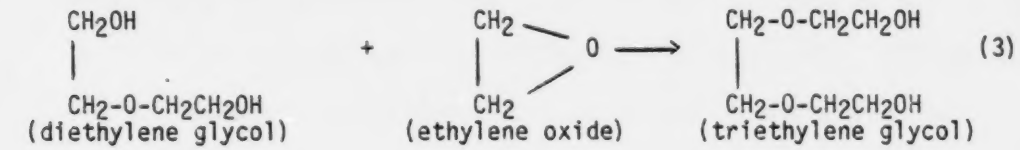
2.2.1 Process Description/Ethylene Glycol. Ethylene glycol is manufactured by the addition of water to ethylene oxide (EO) in a noncatalyzed pressure hydration process. The ethylene glycol (EG) formed will react with additional ethylene oxide to form diethylene glycol (DEG), triethylene glycol (TEG), and other higher homologs. The chemical equations are as follows:



(1)



(2)



(3)

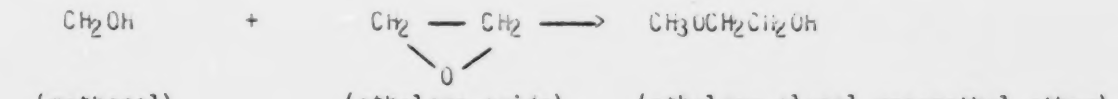
The normal weight ratios of co-products formed are 87 to 88.5 wt. percent ethylene glycol, 9.3 to 10.5 wt. percent diethylene glycol, and 2.2 to 2.5 wt. percent triethylene glycol. These three products constitute an overall yield of 92.5 to 95.5 percent of theoretical, based on the ethylene oxide feed.

Figure 2-3 represents a typical noncatalyzed ethylene oxide hydration process. The continuous process is carried out in the liquid phase, and the reactions are strongly exothermic. Theoretically, 0.71 kg of EO is required to produce 1 kg of EG; 0.83 kg of EO is required to produce 1 kg of DEG; and 0.88 kg of EO is required to produce 1 kg of TEG.

Refined liquid EO (S1), makeup water (S2), and recycle water are mixed under pressure (1,380 kPa), preheated, and fed to the hydrolyzer. The feed solution (S3) contains approximately 8 kg of water per kg of EO. The reactor effluent, heated by the exothermic heat of hydration, exists (S4) the hydrolyzer at 200°C and enters a multiple-effect evaporator system for removal of water.

A portion of the vapor from the first evaporator effect is purged (S5) to remove light impurities from the system. The remainder of the vapor and the vapors from the remaining evaporator effects are condensed and recycled (S6). The evaporator calandria and the condenser on the final evaporator effect are vented (A) to remove noncondensable gases.

2.2.2 Process Description/Glycol Ethers. The ethylene glycol monoethers are produced by the following sodium hydroxide catalyzed chemical reactions. Only the reactions with methanol are shown; however, the primary alcohols, ethanol, and butanol, react similarly to produce the ethyl and butyl ethers.



(methanol) (ethylene oxide) (ethylene glycol monomethyl ether)

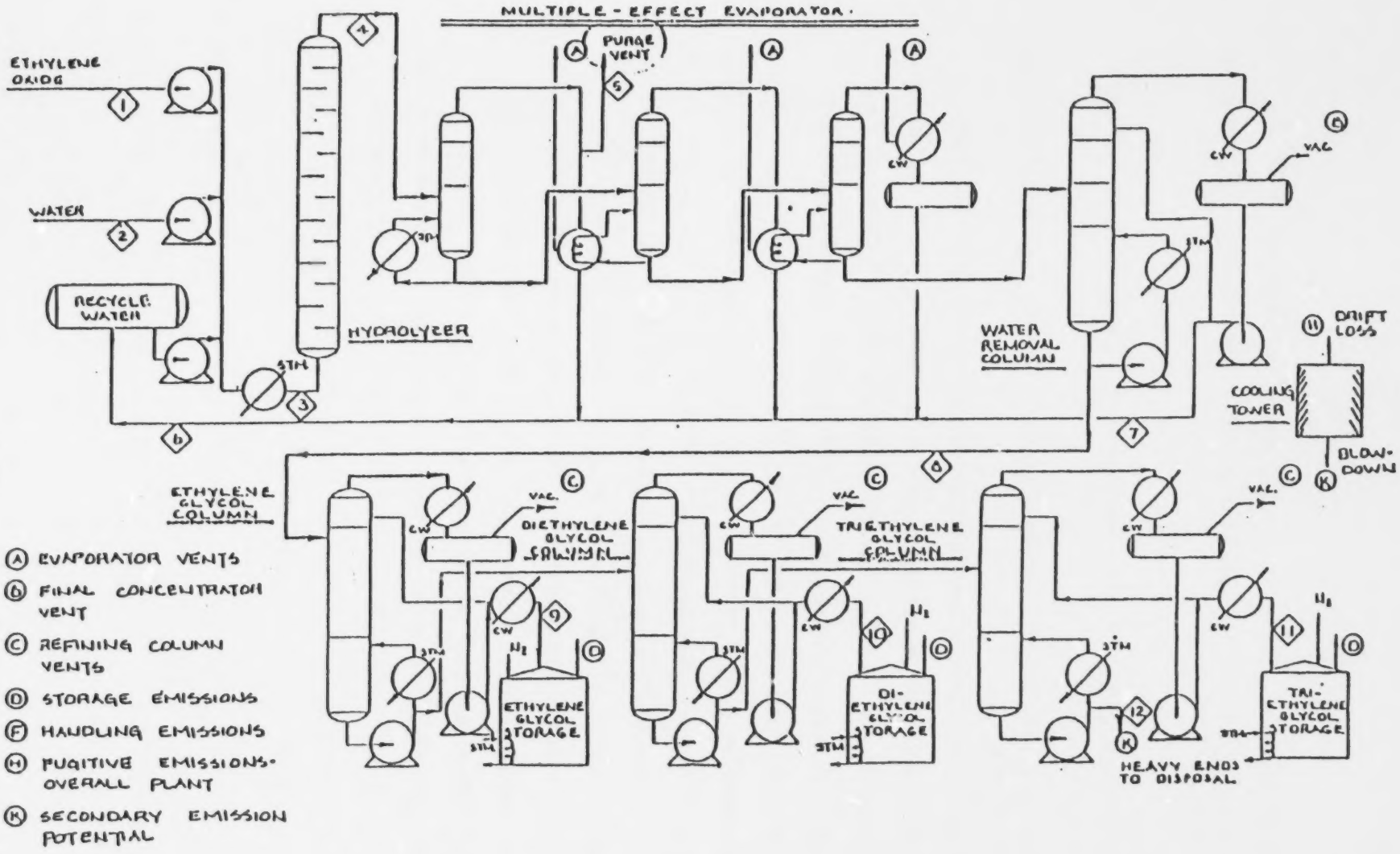
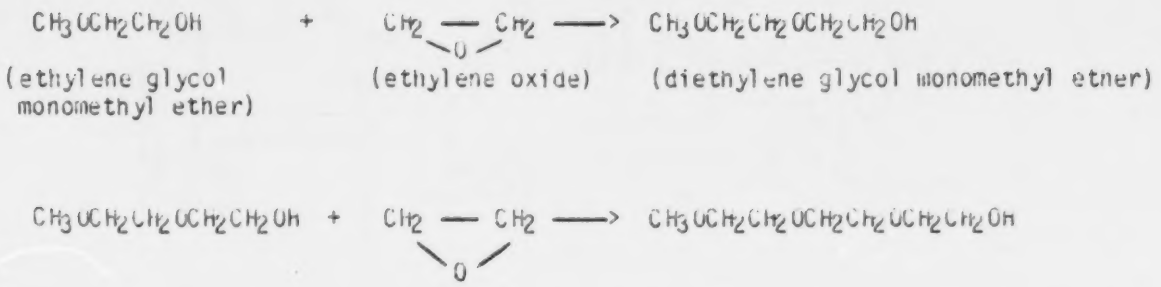


Figure 2-3. Production of Ethylene Glycol by Noncatalyzed Hydration of Ethylene Oxide[5]



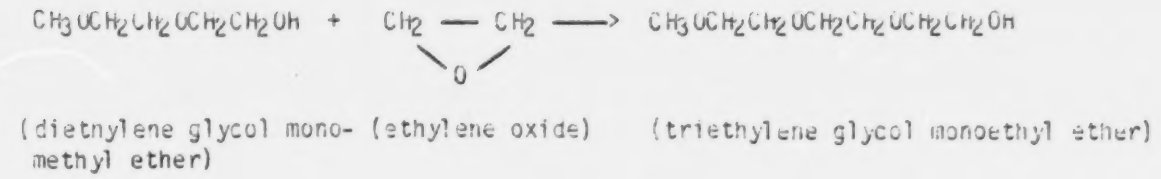


Figure 2-4 represents a continuous process for the manufacture of the glycol ethers. The sodium hydroxide catalyst (S1) and one of the anhydrous primary alcohols (S2) - are blended in the mix tank. The material from the alcohol catalyst storage tank is combined with ethylene oxide (S3) and with the recycled alcohol (S4) and is then fed to the reactor. The exothermic reaction is carried out at an elevated pressure (2.5×10^6 to 4.6×10^6 Pa) and temperature (200 to 230°C).

The product (S5) exits the reactor and is sent to the alcohol distillation column, where excess alcohol is distilled overhead and recycled (S6) for future reaction. The alcohol column bottoms (S7) are then sent to the monoethylene glycol ether column, where monoethylene glycol ether is vacuum distilled and sent (S8) to product storage. Diethylene glycol ether and triethylene glycol ether are vacuum distilled consecutively in two more distillation columns. The diethylene glycol ether product (S9) and triethylene glycol ether product (S10) streams are sent to their respective storage tanks.

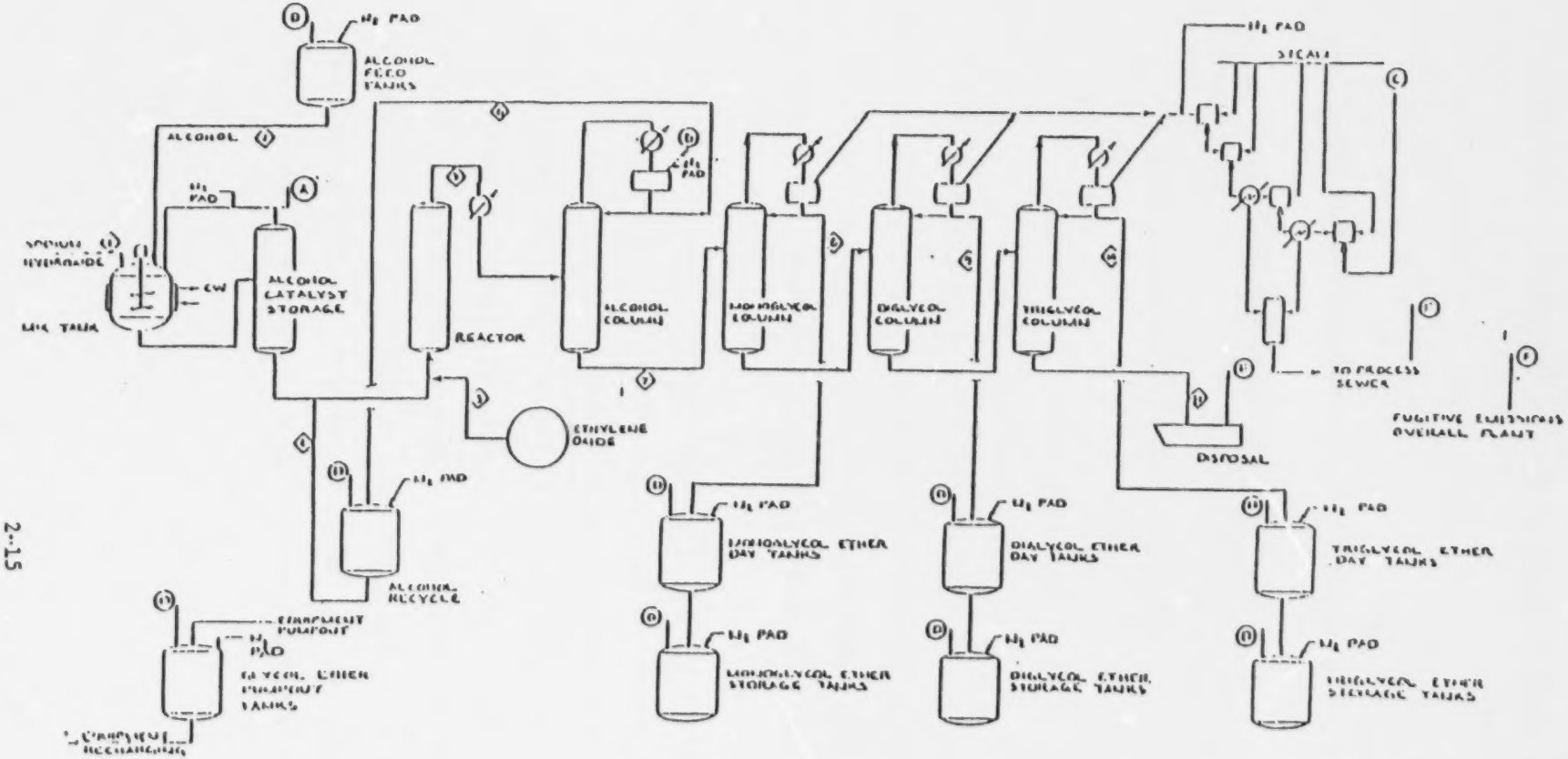
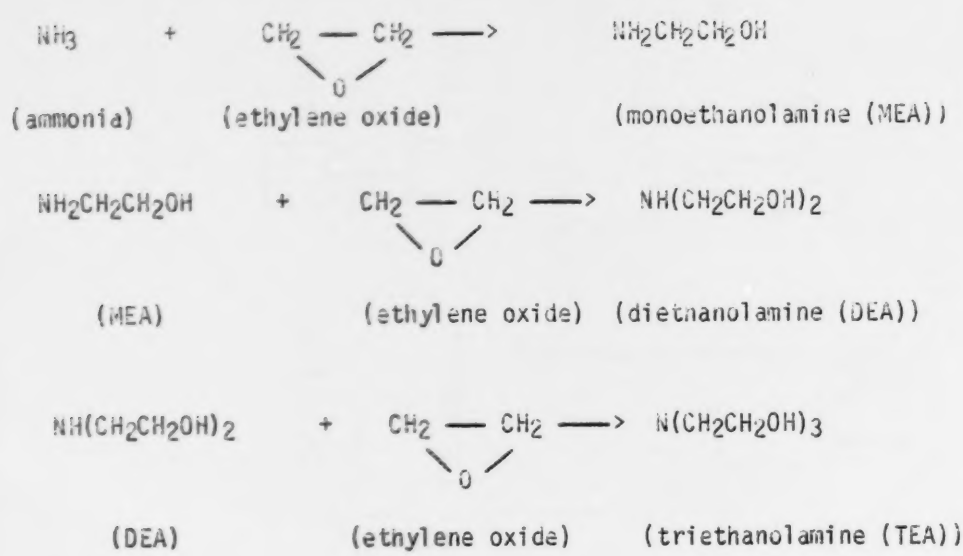


Figure 2-4. Production of Glycol Ethers from Ethylene Oxide[5]

2.2.3 Process Description/Ethanolamines. Ethanolamines are produced by the following series:


NH3 + CH2 — CH2 ——> NH2CH2CH2OH
O
(ammonia) (ethylene oxide) (monoethanolamine (MEA))
NH2CH2CH2OH + CH2 — CH2 ——> NH(CH2CH2OH)2
O
(MEA) (ethylene oxide) (diethanolamine (DEA))
NH(CH2CH2OH)2 + CH2 — CH2 ——> N(CH2CH2OH)3
O
(DEA) (ethylene oxide) (triethanolamine (TEA))

The process is noncatalytic, strongly exothermic, and is carried out in the liquid phase in the presence of water. The distribution of products is dependent on the ratio of ammonia to ethylene oxide used; excess ammonia favors MEA formation.

The continuous manufacture of ethanolamines is shown schematically in Figure 2-5. Ethylene oxide (S1) and aqueous ammonia (S2) are fed to a reactor. The reaction conditons usually are a temperature range of 50 to 100°C, a pressure of 1 to 2 MPa, and an excess of 28 to 50 percent aqueous ammonia. The reactor effluent (S3) is stripped of unreacted ammonia and some water (S4) in an ammonia stripper operated under pressure. This ammonia, together with fresh feed (S5), is absorbed in recycled water in the ammonia absorber and fed back to the reactor (S2). The noncondensable overhead gas (S6) from the ammonia stripper is scrubbed of amonia in an

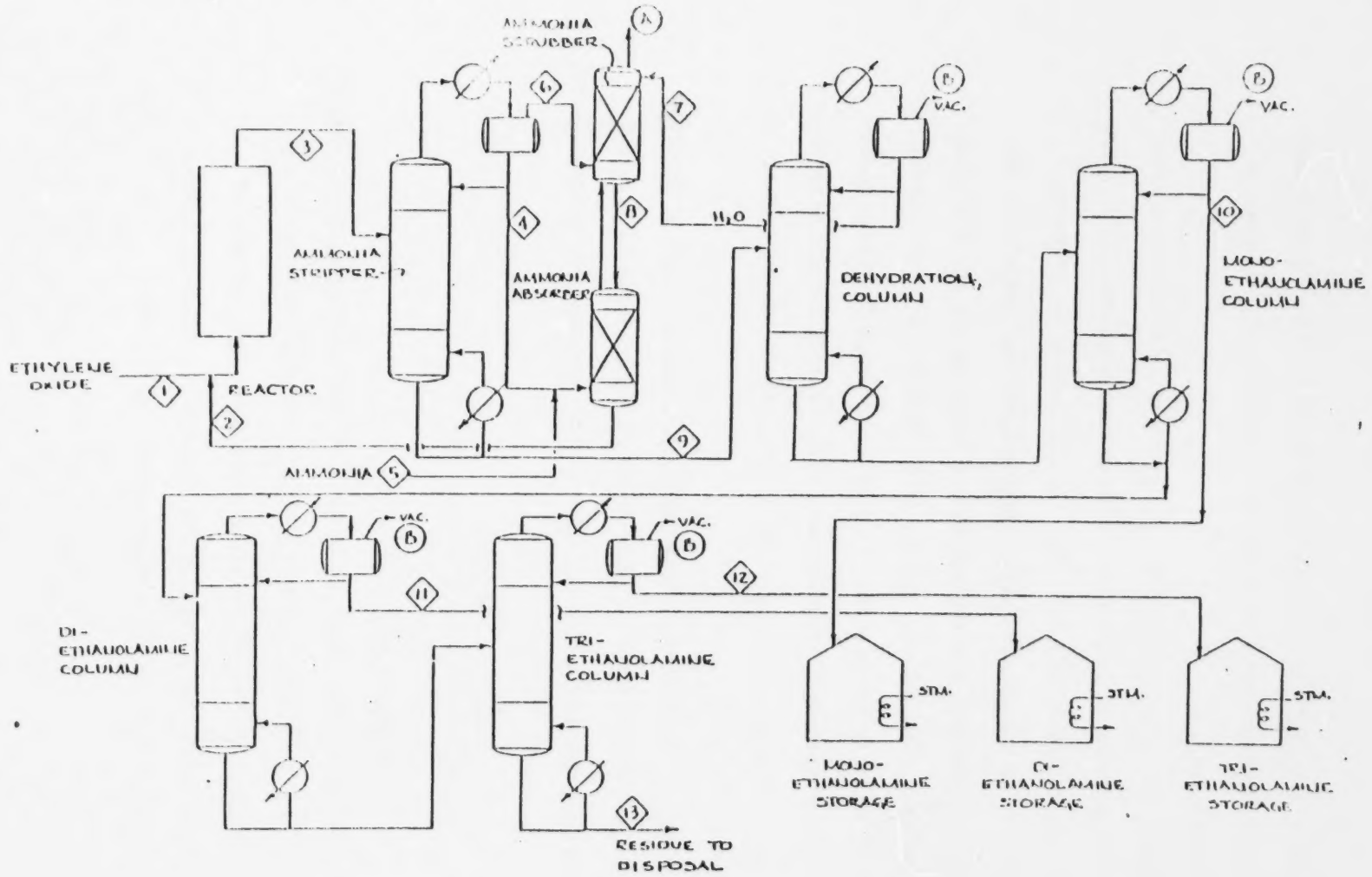


Figure 2-5. Production of Ethanolamines by the Ethylene Oxide--Ammonia Process[5]

ammonia scrubber with recycle water (S7) and is vented (A). Inert gases enter the system with the ethylene oxide feed, which is stored under a nitrogen pressure pad.

The ammonia stripper bottoms (S9) are vacuum distilled in a series of distillation columns to sequentially remove overhead water (S7), which is recycled, and MEA, DEA, and TEA (S10, 11, 12), which are products. Noncondensables from the vacuum distillation columns are vented (B) from the vacuum-jet discharges, and the vacuum-jet waste waters are discarded to waste treatment. The bottoms residue (S13) from the triethanolamine column is sent to waste treatment or is sold. The product storage tanks are ordinarily equipped with steam-heating coils to keep the products liquid and are padded with a dry inert gas such as nitrogen to prevent product discoloration.

2.3 Ethoxylation.[3] Detergent alcohol ethoxylates are produced by reacting detergent linear alcohols with ethylene oxide in the presence of a base catalyst such as potassium hydroxide. The general reaction may be represented as follows:

$$ROH + n\,CH_2\!-\!CH_2 \xrightarrow{KOH} RO(CH_2CH_2O)_nH$$

(ethylene oxide)

The molar ratio of ethylene oxide to alcohol in the final product may vary from 2 to 40. Ethoxylates produced for subsequent conversion to alcohol ether sulfates usually contain 3 moles of ethylene oxide per mole of alcohol. Products made for direct use as nonionic surfactants usually contain 6 to 12 moles of ethylene oxide per mole of alcohol.

2.4 Sterlization/Fumigation. The type of equipment used for EO fumigation/ sterilization varies with the application. The basic types of equipment are discussed in the following sections.

Vacuum Chambers. Vacuum chambers are pressure vessels with a vacuum pump to remove air from the chamber before sterilization begins and to remove some of the EO/air mixture after sterilization. Though the units vary widely in size and design features, the operating procedure is essentially as follows:

1. Contaminated material is loaded into the chamber.
2. The hermetically sealed door is closed.
3. Air is vacuumed from the chamber.
4. The sterilant pure (100%) EO, 12 percent EO/88 percent Freon, or 10 percent EO/90 percent carbon dioxide is introduced into the chamber to a set pressure or concentration and for a specified time period. Pure (100%) EO is used with negative pressure; EO mixtures are used with positive pressure. Pressure, concentration of sterilant, and time period are adjusted for the individual situation.
5. An exhaust vacuum removes the EO or EO/gas mixture from the chamber. The EO or EO/gas mixture is vented through a vent line to the atmosphere or to a sewer drain.
6. Fresh air is drawn into the chamber until atmospheric pressure is reached.
7. The door is opened and the treated material removed.
8. The treated material may be transferred to an aeration cabinet which circulates heated air around the material until residual EO has escaped. (Aeration cabinets are used almost exclusively in hospitals).

Small countertop models with capacities less than 0.1m^3 (<4ft^3) are most commonly used in health care and health diagnosis facilities. In hospitals they are used in areas such as operating rooms. One industrial use is in the manufacture of contact lenses. EO is supplied either in single-dose cartridges of pure (100%) EO or in pressurized cylinders of 12 percent EO/88 percent Freon. Small chambers generally vent directly into the atmosphere through a length of tubing. Some models vent into a sponge kept damp in a bucket of water.

Intermediate-sized chambers of from 0.1 to 2.8m^3 (4-100 ft^3) are used primarily in hospital central supply facilities. They are also used in research and industrial facilities, libraries, museums, and beehive fumigation facilities. An EO mixture is supplied in pressurized cylinders. Intermediate-sized chambers of this type may vent emissions to the atmosphere or the emissions may be mixed with water which is routed to a sewer drain.

Large chambers with capacities greater than 2.8 m^3 (100 ft^3) are used primarily for industrial sterilization of medical products, spices, and other products. They may be as large as 85 m^3 (3000 ft^3) in capacity and are custom-made. In such large capacity custom chambers, an EO mixture or pure (100%) EO is fed from pressurized cylinders or from large tanks. Emissions from large sterilizers are typically evacuated using once-through water-ring vacuum pumps. For these pumps, the amount of ethylene oxide absorbed in the water is generally less than 30 percent due to the relatively low gas retention time. Ethylene oxide absorbed in the water can desorb to the workplace above the break between the liquid pipe and drain.

3. NATIONWIDE EMISSIONS

Chapter 3 provides nationwide ethylene oxide emission estimates from each of the processes described in Chapter 2. Estimates are provided for the following emission sources: Equipment leaks (valves, pumps, compressors, etc.) cooling towers, vents, storage and loading operations, ethoxylation, sterilization/fumigation, and effluents. These estimates represent baseline (present) emission levels.

Detailed emission data and corresponding process parameters from each ethylene oxide production site were provided to the EPA from each operator. Information was provided including emission stream characteristics (flow rate, temperature, composition, etc.) to and from control devices and vents to atmosphere where no device was used. Data were provided for all process vent emission sources, storage and loading operations, and effluents for the entire plant site including captive uses. Equipment component counts for pump seals, compressors, flanges, valves, pressure relief devices, sample connections, and open ended lines were provided for all equipment handling streams with any ethylene oxide present.

The equipment leak component counts from all the plants were used to develop model plants for both the oxygen and air oxidation processes. Emission factors for the synthetic organic chemical manufacturers industry (SOCMI) were applied to these model plants to establish baseline emissions and controlled emission levels. This approach assumes standard industry practice for control of equipment leaks for the baseline case.

National emissions for cooling towers, vents, storage and loading facilities, and effluents for production facilities are the emissions reported by the plants to EPA. Equipment component leak emissions were estimated using EPA emission factors. Ethylene oxide flow rates (kg E.O./10^3 kg E.O.

capacity), to and from control devices, were developed for each emission source based on plant data. This information provides control efficiencies and a means of comparing the relative magnitude of each emission source.

Data from only one plant forms the basis for emission estimates for ethoxylation produciton. It was assumed that the major source of emissions is from leaking equipment. The model plant for ethoxylate producer facilities was based on comparison of equipment counts from the one ethoxylate plant and the ethylene oxide production sites. For rough emission estimates it was assumed that ethoxylate producers have about 10 percent of the components of ethylene oxide production sites; the estimate probably overstates emissions from these facilities. Data is needed for a more accurate estimate.

It was assumed that the typical sterilization and fumigation facility vents all the ethylene oxide used in process to the atmosphere. Emission estimates were then based on national estimates of the ethylene oxide consumed in these processes.

Total nationwide ethylene oxide emissions from production, ethoxylation, and fumigant/sterilant uses are summarized in Table 3-1. Approximately 5,000 metric tons of ethylene oxide are being emitted per year. The average producer, sterilizer/fumigator, medical facility, and ethoxylator facilities emit approximately 100, 6 to 28, 0.06, and 4 metric tons per year of ethylene oxide respectively (see Table 3-2).

3.1 Production Facilities

Emission sources at production facilities include equipment leaks, cooling towers, vents, storage and loading, and effluent treatment facilities.

TABLE 3-1. NATIONAL EMISSIONS
ETHYLENE OXIDE
(Mg/Yr)

Source		Emissions Mg/Yr	Emissions % Subtotal
A. Ethylene Oxide Production Facilities[1]			
1. Equipment Leaks		1,180	78
2. Cooling Towers		190	13
3. Vents		100	6
4. Storage & Loading		40	3
5. Effluents		10	< 1
	Subtotal	1,520	100
B. Surfactant Production (Equipment Leaks)	Subtotal	< 200	100
C. Fumigant/Sterilant Use[2]	Subtotal	2,600-3,900[3]	100
	TOTAL	4,320-5,620	

1 Includes captive use of ethylene oxide in production of (a) ethylene, diethylene, and triethylene glycol, (b) glycol ethers, (c) ethanolamines (d) polyethylene glycol and nonionic surface active agents

2 Assumes all ethylene oxide is emitted to atmosphere

3 Reinhart, Joe. Officer of Pesticides Programs, U.S. Environmental Protection Agency. Memo to Carolyn Smith, Radian Corporation, May 1983.

Table 3-2. AVERAGE FACILITY EMISSIONS

(Mg of EO/yr)

Facility	Number of Facilities	National Emissions (Mg)	Emissions Per Facility (Mg)
Production	15	1,520	100
Sterilizers/Fumigators	100-450	2,800	6-28
Medical Facilities	6,000-10,000	400	<0.06
Surfactant Production	50	200	4
	Total	4,920	

3.1.1 Equipment Leaks

Equipment leaks are those emissions that result when process fluid (either liquid or gaseous) leaks from plant equipment. There are many potential sources of equipment leaks in a typical synthetic organic chemical plant. The following sources are considered in this report: pumps, compressors, in-line process valves, pressure relief devices, open-ended valves, sampling connections, and flanges. Emissions which result from leaks in these types of equipment are generally random occurrences which cannot be predicted.

A complete description of each type of equipment leak is addressed in the background information document: "VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry - Background Information for Proposed Standards," EPA-450/3-80-033a, November 1980. The number of equipment components subject to leakage for both the oxygen and air oxidation model plants are summarized in Table 3-3. Emission factors, component emissions, and total model plant emissions are summarized for both oxygen and air oxidation model plants in Tables 3-4 and 3-5.

3.1.2 Cooling Towers

Cooling towers are found in the oxygen-oxidation plants where more heat is released than in the air oxidation process. The purpose of these towers is to cool the plant's recirculated effluent from the ethylene oxide stripper column. The cooling process is achieved by evaporation when the process cooling water and air are contacted. The emission rate is inversely proportional to the efficiency of the stripper column in removing ethylene oxide. Approximately 0.07 Kg of ethylene oxide are emitted for each 1000 Kg of ethylene oxide capacity.

Table 3-3. Model Plant Components for Ethylene Oxide Production Facilities

		Number of Components [1]	
		O_2 - Oxidation[2]	Air - Oxidation[3]
Pump Seals	Packed	4	0
	Mechanical	16	11
	D - Mechanical	10	16
Compressors		3	6
Flanges		1738	1214
Valves	Gas	177	200
	Liquid	693	581
Press. Rel. Dev.	Gas	26	60
	Liquid	15	40
Sample Conn	Gas	18	55
	Liquid	22	90
Open Ended Lines	Gas	38	70
	Liquid	122	122

[1] Includes captive feed processing components

[2] Average of six facilities component counts: Average EO capacity = 1 x 10^5 mtons/yr

[3] Average of five facilities component counts: Average EO capacity = 3.6 x 10^5 mtons/

Table 3-4. Ethylene Oxide Equipment Leak Emissions
Ethylene Oxide Production: Air-Oxidation
Model Plant

Emissions Source	Number of Sources	Emission Factor [a] (kg/day/source)	Adjustment Factor[b]	Annual Emissions, (Mg/yr)[c]
Pump Seals				
Light Liquid	27	1.19	.5	5.8
Heavy Liquid	--	--	--	--
Valves				
Gas	200	0.13	.5	4.8
Light Liquid	581	0.17	.5	18.0
Heavy Liquid	--	--	--	--
Safety/relief valves Gas	60	2.5	.5	27.4
Open-ended lines	192	0.04	.5	0.0[d]
Compressors	6	5.47	.5	5.9
Sampling connections	145	0.36	.5	2.4[e]
Flanges	1,214	0.02	.5	4.4
TOTAL				68.7

[a]"Control of Volatile Organic Compound Leaks from Synthetic Organic Chemical and Polymer Manufacturing Equipment," EPA-450/3-83-006, March 1984, p. 2-21.

[b]The emission factor assumes 100 percent organic in stream and must be adjusted for ethylene oxide emission estimates to account for the different percent of ethylene oxide in various streams. Assume the average stream contains 50 percent ethylene oxide.

[c]For estimating purposes, one operating year was assumed to be 365 days.

[d]All open-ended lines (in model unit) are assumed to be controlled at baseline; therefore, there are no associated emissions.

[e]Seventy-five percent of sampling connections are assumed to be controlled at baseline; therefore, the emissions are based on 36 of 145 sampling connections.

Table 3-5. Ethylene Oxide Equipment Leak Emissions
Ethylene Oxide Production: Oxygen-Oxidation
Model Plant

Emissions Source	Number of Sources	Emission Factor [a] (kg/day/source)	Adjustment Factor[b]	Annual Emissions, (Mg/yr)[c]
Pump Seals				
Light Liquid	30	1.19	.5	6.5
Heavy Liquid	--	--	--	--
Valves				
Gas	177	0.13	.5	4.2
Light Liquid	693	0.17	.5	21.5
Heavy Liquid	--	--	--	--
Safety/relief valves Gas	26	2.5	.5	11.8
Open-ended lines	160	0.04	.5	0.0[d]
Compressors	3	5.47	.5	2.9
Sampling connections	40	0.36	.5	0.6[e]
Flanges	1,738	0.02	.5	6.4
TOTAL				53.9

[a]"Control of Volatile Organic Compound Leaks from Synthetic Organic Chemical and Polymer Manufacturing Equipment," EPA-450/3-83-006, March 1984, p. 2-21.

[b]The emission factor assumes 100 percent organic in stream and must be adjusted for ethylene oxide emission estimates to account for the different percent of ethylene oxide in various streams. Assume the average stream contains 50 percent ethylene oxide.

[c]For estimating purposes, one operating year was assumed to be 365 days.

[d]All open-ended lines (in model unit) are assumed to be controlled at baseline; therefore, there are no associated emissions.

[e]Seventy-five percent of sampling connections are assumed to be controlled at baseline; therefore, the emissions are based on 5 of 40 sampling connections.

3.1.3 Vent Emission Sources

3.1.3.1 Air Oxidation

The main process vent is the largest vent source of ethylene oxide emissions in the air oxidation plant. The vent gases also contain nitrogen, unreacted oxygen from the air feed, ethane and ethylene from the ethylene feed, and by-product CO_2. The main process gases are vented to a thermal or catalytic oxidizer; inlet and outlet (to atmosphere) mass flow rates of ethylene oxide are summarized in Table 3-6.

The ethylene oxide stripper vent releases inert gases and ethylene which were absorbed into the main and purge absorber waters. The stripper vent stream is combusted in a boiler resulting in approximately 100 percent control of ethylene oxide.

In some plants, vent streams are routed to an absorber to recover ethylene oxide. The vent stream from the absorber is then fed to a boiler or plant flare; emission levels are approximately zero.

3.1.3.2 Oxygen Oxidation

The volume of the main process vent or argon vent of the oxygen oxidation process is much less than that of the corresponding vent in the air process. This vent contains mainly argon and nitrogen from the oxygen feed, ethane from the ethylene feed, and very small amounts of ethylene oxide (< 0.01 mole %). The ethylene content of the main process vent is sufficient to support combustion and is routinely routed to a boiler or incinerator; ethylene oxide emissions are approximately zero from this source. Inlet and outlet mass flow rates of ethylene oxide are summarized in Table 3-7.

Table 3-6. CONTROL TECHNIQUES & EMISSION RATES[a]

AIR OXIDATION

Principal Source	Control Units	Control Efficiency (%)	E.O.: Flow Rate ($kg/10^3 kg$ Capacity) Control Unit	
			Inlet	Outlet
VENT SOURCES:				
A. Main Process	a. Thermal Oxidation	80	.2	.04
	b. Catalytic Oxidation	100	.005	0
			Avg. .10	.02
B. Vent Absorber	a. Boiler	100	4×10^{-5}	0
	b. Plant Flare	99	0	-
			Avg. 4×10^{-5}	0
C. E.O. Stripper	Boiler	100	unknown	unknown

[a]Based on data provided by ethylene oxide producers

Table 3-7 . CONTROL TECHNIQUES & EMISSION RATES[a]
OXYGEN OXIDATION

Principal Source	Control Units	Control Efficiency (%)	E.O.: Flow Rate ($kg/10^3 kg$ Capacity) Control Unit	
			Inlet	Outlet
I. VENT SOURCES:				
A. Argon	a. Boiler	100	.0011	0
	b. Boiler	100	.0016	0
	c. Incinerator	99.9	.002	0
			Avg. .0016	0
B. CO_2 Stripper	a. Carbonate Flasher and Vent Condenser	92	.75	.06
	b. CO_2 Recovery	100	.009	0
	c. Methanol Unit	100	.00063	0
CO_2 Regenerator	a. N.A. (to sale)	100	.002	
			Avg. .19	.06
C. E.O. Stripper	a. Uncontrolled	N.A.	.04	---
	b. Recylce to reabsorber	---	---	---
	c. Cooling tower	0	unknown	unknown
E.O. Reabsorber	a. Recycle	100	.002	0 or .002[a]
	b. Incineration	99.95	.065	0
E.O. Purification	a. H_2O Scrubber	85	unk	trace
	b. Vent absorber	99.99+	11.4	.0004
	c. Recycle to reabsorber	---	---	---
			Avg. 2.9	.0004 - .0024

[a]Based on data provided by ethylene oxide producers

More than 99 percent of the CO_2 from the CO_2 absorber is processed to recover CO_2. Also, a carbonate flasher followed by a vent condenser is being used to reduce atmospheric emissions. The average ethylene oxide emission rate from the CO_2 vent is approximately 0.06 Kg per 1000 Kg of ethylene oxide capacity (Table 3-7).

The ethylene oxide stripper purge vent is composed of inert gas, ethylene, and ethylene oxide that were dissolved in the main absorber water during the recovery of ethylene oxide from the reaction gases. After ethylene oxide is desorbed from the water, the purge vent gases are stripped from the ethylene oxide. Typically, ethylene oxide in this stream is scrubbed with water via an absorber and recyled to the process.

An alternative to stripping inerts from the ethylene oxide stream is to vent these gases from the reabsorber tower when ethylene oxide is reabsorbed in water. The process sequence is reactor, scrubber, stripper (ethylene oxide stripped from water), and ethylene oxide reabsorber. The vent stream from the reabsorber can be incinerated.

Inert gases are also purged from the ethylene oxide purification tower. This stream can be scrubbed, vented to an absorber, and recycled to a reabsorber; atmospheric emissions from this vent are negligible (Table 3-7).

3.1.4 Storage & Loading

Ethylene oxide is a gas at ambient termeratures. Therefore, ethylene oxide is stored at approximately 10°C in insulated or underground tanks to maintain it as a liquid. Tanks are generally blanketed with nitrogen for safety purposes. Vapors displaced during storage and railcar loading operations are recycled to the process or scrubbed prior to flaring or incineration at most facilities. Emissions from storage and loading are reduced to negligible amounts with the exception of one producer facility where a

caustic scrubber is utilized emitting approximately 39 Mg per year.

3.2 Ethoxylation

Most ethoxylation facilities produce surface active agents (surfacants). Ethylene oxide is received by pressurized railcar, stored, then reacted with various chemicals in a closed process. The primary source of ethylene oxide emissions is assumed to be equipment leaks, although minimal data has been collected. Other emissions sources at these facilities are assumed to be negligible. Control techniques specified in both the synthetic organic chemical manufacture industry (SOCMI) fugitive emissions NSPS and CTG would effectively reduce ethylene oxide emissions by approximately 75 and 40 percent respectively.

It was assumed that component counts at these facilities (minus flanges) were approximately 10 percent of those at ethylene oxide production facilities.

3.3. Fumigation/Sterilization

Ethylene oxide emissions result from fumigation and sterilation operations when chambers are purged to the atmosphere. Emissions from these facilities is based on estimates of ethylene oxide used by these facilities. Approximately 2,800 metric tons of ethylene oxide is used in these industries and ultimately vented to the atmosphere.

4. CONTROL TECHNIQUES

4.1 Equipment Leaks

Primary control methods for equipment leaks include leak detection and repair (LDAR) methods and control equipment. Leak detection methods are used to identify equipment components that are emitting significant amounts of volatile organic chemicals. Emission from leaking sources may be reduced by three general methods: repair, modification, or replacement of source. In the case of open-ended lines, however, equipment leaks are treated more effectively by installation of control equipment.

The U.S. Environmental Protection Agency has proposed new source standards (NSPS) and published control guidelines (CTG) for new and existing facilities in the synthetic organic chemical industry. Both the NSPS and CTG are applicable to ethylene oxide production and ethoxylator facilities. A summary of the CTG and NSPS control levels are included in Table 1 for comparison. The CTG and NSPS background information document, can be consulted for a detailed description of the individual component control techniques (see Table 4-1 footnotes).

Control efficiencies for individual equipment components under the CTG and NSPS level of control are provided in Table 4-2.

Table 4-1 EQUIPMENT LEAKS

CONTROL TECHNIQUES

Emission Source	Control Technique	
	CTG[1]	NSPS[2]
Pump Seals (Light Liquid)	LDAR[3] (quarterly monitoring)	LDAR (monthly monitoring)
Valves (Gas) (Light Liquid)	LDAR (quarterly monitoring)	LDAR (monthly monitoring)
Safety/relief valves (Gas)	LDAR (quarterly monitoring)	Performance standard+
Open-ended Lines	Caps	Caps
Compressors	LDAR (quarterly monitoring)	Seal System
Sampling connections	none	Closed Purge System

1 "Control of Volatile Organic Compound Leaks From Synthetic Organic Chemical and Polymer Manufacturing Equipment," EPA-450/3-83-006, March 1984.

2 "VOC Fugitive Emissions in Synthetic Organic Chemicals Manufacturing Industry - Background Information for Proposed Standards, "EPA-450/3-80-033a, November, 1980.

3 LDAR - Leak Detection and Repair Model

4 No detectable emissions

Table 4-2. Control Efficiencies: CTG & NSPS

Equipment Components

Emissions Source	Emission Factor[a] (kg/day/source) (uncontrolled)	Present Control Efficiency	
		CTG	NSPS
Pump Seals Light Liquid	1.19	0.33	0.61
Valves			
Gas	0.13	0.64	0.73
Light Liquid	0.17	0.44	0.59
Safety/relief valves			
Gas	2.5	0.44	1.0
Open-ended lines	0.04	1.0	1.0
Compressors	5.47	0.33	1.0
Sampling connection	0.36	0.0	1.0

4.2. Cooling Towers

Two basic techniques are available for controlling cooling tower emissions. Emissions can be reduced by either using a sealed heat exchanger or using a more efficient stripper column(s).

4.2.1. Heat Exchanger

A heat exchanger used in place of a cooling tower would virtually eliminate ethylene oxide emissions. It was assumed that the incremental cost of utilizing a heat exchanger in place of a conventional cooling tower is prohibitive. Therefore, heat exchangers are not considered a viable approach to reducing cooling tower emissions.

4.2.2. Stripper Column Design

4.2.2.1. New Sources

Recirculated effluent from the ethylene oxide stripper column to the cooling tower results in ethylene oxide emissions when water contacts the atmosphere. Emission can be reduced by utilizing higher efficiency trays and packing internals to increase stripper column effectiveness. More efficient stripper columns require less energy for processing; this energy saving may off-set the cost of additional trays or more costly packing.

4.2.2.2. Existing Sources

Although existing stripper columns can be redesigned to incorporate additional trays, it is most likely too costly. Because packing trays are welded in place, a retrofit of an existing column requires cutting out old trays to replace with new ones.

A stripping efficiency of existing towers can be increased by replacing packing materials with more efficient packing.

4.2.2.3. Emission Reduction

An emission reduction of roughly 80 percent appears possible for new facilities utilizing both optimum tray and packing design. Existing facilities with only new packing intervals would experience less than an 80 percent emission reduction.

4.3 Vents

As discussed in section 2.1.3., nearly all vent streams from ethylene oxide production facilities are recycled to the process or combusted. In the oxygen oxidation process the CO_2 stripper or regenerator vent is processed to recover CO_2. Present (baseline) control levels are summarized in Table 6 and 7 of Section 3.

4.4 Sterilization and Fumigation

Ethylene oxide emissions vented from sterilizer and fumigator chambers may be combusted or processed for recovery.

4.4.1 DEOXX™

The DEOXX™ system was designed by Chemrox, Inc. to chemically process ethylene oxide vapors to saleable ethylene glycol. The system has been certified by New York State as best available control technology (BACT) and appears to have established the 99 percent efficiency level as BACT in New York. The DEOXX™ system is under patent review. DEOXX™ ethylene oxide emission control systems have been or are scheduled to be installed in the states of New York, Maryland, Michigan, Utah, Hawaii, California, Florida, Connecticut, Texas, Rhode Island, Illinois, Pennsylvania, Puerto Rico, South Carolina, and Minnesota.[10]

5. CONTROL TECHNIQUE COSTS

Annualized control costs, emission reductions, and cost effectiveness for each emission source are summarized in Table 5-1. The cost analysis was calculated on a model plant basis for equipment leak sources.

5.1 Equipment Leaks

5.1.1. Ethylene Oxide Production

Total annual equipment leak control costs are provided in Table 5-2 for both the oxygen and air oxidation model plants. Model plant emission sources, emissions, and emission reductions are summarized in Table: 5-3a and 5-3b. The annualized cost per metric ton of ethylene oxide reduced is $1,800 for oxygen - oxidation plants and $1,200 for air-oxidation facilities. These costs and emission reductions reflect the new source performance standard level of control; detailed costs are provided in the Appendix A.

5.1.2. Ethoxylation

Ethoxylation equipment leak control costs are provided in Table 5-4. Equipment counts were assumed to be 10 percent of ethylene oxide production facilities. Annualized cost per metric ton of ethylene oxide reduced is approximately $2,500.

5.2 Sterilization/Fumigation

Capital costs, annualized costs, and cost effectiveness for a DEOXX™ system treating approximately 90 metric tons of ethylene oxide is summarized in Table 5-5. Annualized costs per metric ton of ethylene oxide reduced is approximately $450.

Table 5-1. Preliminary Control Efficiency and Cost Effectiveness
Ethylene Oxide Emission Sources

Facility/Source	Control Technique	% Emission Reduction	Model Plant Annual Cost (1983 $)	Model Plant Emiss. Reduction (Mg/yr)	Model Plant Cost Effect ($/Mg)
I. Production					
A. Equipment Leaks	NSPS SOCMI Std				
1. Oxygen Oxidation	for Equipment Leaks	65	64,300[a]	35[b]	1,800
2. Air Oxidation		80	63,600[a]	54[b]	1,200
B. Cooling Towers	Repacking stripper column	80	unknown	20	unknown
C. Vents					
1. Argon	Boiler/Incinerator	99.9		- Baseline -	
2. CO_2 Stripper	Carbonate Flasher and Vent Condenser	92		- Baseline -	
3. E.O. Stripper, Reabsorber, or Purification	Recycle to Process	99.9		- Baseline -	
II. Ethoxylation/Equipment Leaks	NSPS SOCMI Std for Equipment Leaks	70	12,400[c]	5[c]	2,500
III. Sterilizers & Fumigators	DEOXX™	99	39,800[d]	87	450

[a]From Table 5-2

[b]From Table 5-3

[c]From Table 5-4

[d]From Table 5-5

TABLE 5-2. EQUIPMENT LEAK CONTROL COSTS[a] ETHYLENE OXIDE PRODUCTION

Source/Process	Model Plants Total Annual Cost (Oct 1983 $) Oxygen Oxidation	Air Oxidation
Pumps	10,090	8,890
Valves	57,040	51,200
Safety/Relief Valves	7,840	16,800
Open-Ended Lines	0	0
Compressors	7,200	14,400
Sampling Connections	1.700	6,120
Monitoring Instruments	7,270	7,270
TOTAL COST	91,140	104,680
Product Recovery Credit	+(26,800)	+(41,040)
NET ANNUAL COST	64,340	63,640

[a]Detailed costs are provided in Appendix.

TABLE 5-3a

EQUIPMENT LEAKS
EMISSIONS AND EMISSION REDUCTION ESTIMATES
ETHYLENE OXIDE PRODUCTION: OXYGEN-OXIDATION
Model Plant

Emissions Source	Number of Sources	Annual Emissions, Mg/yr[a]	Control Technique NSPS	Present Control Efficiency	Emission Reductions, Mg/yr
Pump Seals					
Light Liquid	30	6.5	LDAR	0.61	3.9
Heavy Liquid	--	--		--	--
Valves					
Gas	177	4.2	LDAR	0.73	3.0
Light Liquid	693	21.5		0.59	12.6
Heavy Liquid	--	--		--	--
Safety/relief valves					
Gas	26	11.8	Performance Standard	1.0	11.8
Open-ended lines	0	0.0	CAPS	1.0	0.0
Compressors	3	2.9	Seal System	1.0	2.9
Sampling connections	10	0.6	Closed Purge System	1.0	0.6
Flanges	1,738	6.4	--	--	--
TOTAL		53.9		TOTAL	34.8

[a]From Table 3.5

TABLE 5-3b

EQUIPMENT LEAKS

EMISSIONS AND EMISSION REDUCTION ESTIMATES
ETHYLENE OXIDE PRODUCTION: AIR-OXIDATION
Model Plant

Emissions Source	Number of Sources	Annual Emissions, Mg/yr[a]	Control Technique NSPS	Present Control Efficiency	Emission Reductions, Mg/yr
Pump Seals					
Light Liquid	27	5.8	LDAR	0.61	3.5
Heavy Liquid	--	--		--	--
Valves					
Gas	200	4.8	LDAR	0.73	3.5
Light Liquid	581	18.0		0.59	10.6
Heavy Liquid	--	--		--	--
Safety/relief valves Gas	60	27.4	Performance Standard	1.0	27.4
Open-ended lines	0	0.0	CAPS	1.0	0.0
Compressors	6	5.9	Seal System	1.0	5.9
Sampling connections	36	2.4	Closed Purge System	1.0	2.4
Flanges	1,214	4.4	--	--	--
TOTAL		68.7			53.3

[a]From Table 3.4

TABLE 5-4. EQUIPMENT LEAK CONTROL COSTS: ETHOXYLATION
Model Plant[a]

Source/Process	Total Annual Cost, $
Pumps	950
Valves	5,400
Safety/Relief Valves	1,200
Open-ended Lines	0
Compressors	1,080
Sampling Connections	390
Monitoring Instruments	7,270
TOTAL COST	16,290
Product Recovery Credit	(3,850)[b]
NET ANNUAL COST	12,440

[a]Component counts assumed to be 10% of production facility components. Costs are then 10% of average costs for oxygen and air oxidation model plants (except for monitoring instrument costs).
[b]Emission reduction = 5 mton/yr.

Table 5-5 COST EFFECTIVENESS
DEOXX™ SYSTEM

Cost	1983 $	Annual Cost
Capital Cost (installed)	217,350[a]	25,500[b]
Operating Cost	--	9,300[c]
Local Taxes, Insurance	--	3,500[d]
Administration & Contingency	--	800[e]
Total Annual Costs		39,100
Emission Reduction (Mg/yr)		87[f]
Cost Effectiveness ($/mton)		$ 450

[a]Letter from Anthony Buonicore of Chemrox, Inc. to David Markwordt U. S. EPA dated January 20, 1984. Plant: 87 metric tons of ethylene oxide from 8 sterilizers

[b]Capital Charges assume i = 10% and 20 years equipment life

[c]Letter from Anthony Buonicore of Chemrox, Inc. to David Markwordt, U.S. Environmental Protection Agency, dated August 27, 1984.

[d]1.6% fixed-capital costs

[e]6% of total operating cost (9,300 + 3,500)

[f]Assumed no value for recovered chemical by-product

References

1. Chemical Origins and Markets. Chemical Information Services. Menlo Park, California. Fourth Edition. 1967, p. 12.

2. Chemical Profile: Ethylene Oxide. Chemical Marketing Reporter. June 8, 1981.

3. Chemical Products Synopsis - Ethylene Oxide, Mannsville Chemical Products, December 1982.

4. Ozero, Brian R. and Procelli, Joseph V., Can Developments Keep Ethylene Oxide Viable. Hydrocarbon Processing, March 1984, pp. 55-58.

5. Kalcevic, V. and J.F. Lawson. Ethylene Oxide. In: Organic Chemical Manufacturing, Vol. 9: Selected Processes. (Prepared for U.S. Environmental Protection Agency, EPA-450/3-80-028d). IT Enviroscience. Knoxville, TN. December 1980.

6. Field, D.D., et al. Engineering and Cost Study of Air Pollution Control for the Petrochemical Industry, Vol. 6: Ethylene Oxide Manufacture by Direct Oxidation of Ethylene. (Prepared for U.S. Environmental Protection Agency, Contract No. 68-02-0255). Houdry Division, Air Products and Chemicals, Inc. Marcus Hook, PA. June 1975.

7. Kirk-Othmer Encyclopedia of Chemical Technology. Third Edition, Vol. 9. Etnylene Oxide. John Wiley and Sons. New York, NY. 1980. pp. 432-471.

8. Detergent Alcohols, Chemical Economics Handbook. SRI International, February 1981, p. 601. 5022 T.

9. Letter from Anthony J. Buonicore of Chemrox Inc. to David W. Markwordt of U. S. Environmental Protection Agency, RTP, N. C. January 20, 1984.

10. Letter from Anthony J. Buonicore of Chemrox Inc. to David W. Markwordt of U. S. Environmental Protection Agency, RTP, N. C. August 27, 1984.

APPENDIX A

Equipment Leak Control Costs

for

Ethylene Oxide Model Plants

TABLE 1. EQUIPMENT LEAK CONTROL COSTS[a] ETHYLENE OXIDE PRODUCTION

Source/Process	Model Plants: Total Annual Cost (Oct 1983 $) Oxygen Oxidation	Air Oxidation
Pumps	10,090[d]	8,890[d]
Valves	57,040[b]	51,200[b]
Safety/Relief Valves	7,840[c]	16,800[c]
Open-Ended Lines	0	0
Compressors	7,200[c]	14,400[c]
Sampling Connections	1,700[c]	6,120[c]
Monitoring Instruments	7,270	7,270
TOTAL COST	91,140	104,680
Product Recovery Credit	+ (26,800)[d]	(41,040)[d]
NET ANNUAL COST	64,340	63,640

[a]From Table 3a and 3b.
[b]From Table 5a and 5b.
[c]From Table 7a and 7b.
[d]Value of product recovered = $.35/lb or $770/Mg. Letter from D. C. Macauley, Union Carbide Corporation, to Susan R. Wyatt, U.S. EPA, October 5, 1984.

Table 2a. Emissions and Emission Reduction Estimates
Ethylene Oxide Production: Oxygen Oxidation
Model Plant

Emissions Source	Number of Sources	Emission Factor, kg/day/source	Adjustment Factor[a]	Annual Emissions, Mg/yr[b]	Control Efficiency	Emission Reductions, Mg/yr
Pump Seals						
Light Liquid	30	1.19	.5	6.5	0.61	3.9
Heavy Liquid	--	--	--	--	--	--
Valves						
Gas	177	0.13	.5	4.2	0.73	3.0
Light Liquid	693	0.17	.5	21.5	0.59	12.6
Heavy Liquid	--	--	--	--	--	--
Safety/Relief Valves						
Gas	26	2.5	.5	11.8	1.0	11.8
Open-ended Lines	0	0.04	.5	0	1.0	0
Compressors	3	5.47	.5	2.9	1.0	2.9
Sampling Connections	10	0.36	.5	0.6	1.0	0.6
Flanges	1,738	0.02	.5	6.4	--	--
TOTAL				53.9		34.8

[a]The emission factor assumes 100 percent organic in stream and must be adjusted for ethylene oxide emission estimates to account for the different percent of ethylene oxide in various streams. Assumed the average stream contains 50 percent ethylene oxide.

[b]For estimating purposes, one operating year was assumed to be 365 days.

Table 2b. Emissions and Emission Reduction Estimates
Ethylene Oxide Production: Air Oxidation
Model Plant

Emissions Sources	Number of Sources	Emission Factor, kg/day/source	Adjustment Factor[a]	Annual Emissions, Mg/yr[b]	Control Efficiency	Emission Reductions, Mg/yr
Pump Seals						
Light Liquid	27	1.19	.5	5.8	0.61	3.5
Heavy Liquid	--	--	--	--	--	--
Valves						
Gas	200	0.13	.5	4.8	0.73	3.5
Light Liquid	581	0.17	.5	18.0	0.59	10.6
Heavy Liquid	--	--	--	--	--	--
Safety/Relief Valves						
Gas	60	2.5	.5	27.4	1.0	27.4
Open-ended Lines	2	0.04	.5	0	1.0	0
Compressors	6	5.47	.5	5.9	1.0	5.9
Sampling Connections	36	0.36	.5	2.4	1.0	2.4
Flanges	1,214	0.02	.5	4.4	--	
TOTAL				68.7		53.3

[a]The emission factor assumes 100 percent organic in stream and must be adjusted for ethylene oxide emission estimates to account for the different percent of ethylene oxide in various streams. Assumed the average stream contains 50 percent ethylene oxide.

[b]For estimating purposes, one operating year was assumed to be 365 days.

Table 3a. ANNUAL COSTS OF A LEAK DETECTION AND REPAIR PROGRAM FOR PUMP SEALS--MONTHLY MONITORING: OXYGEN-OXIDATION

Monitoring	Instrument	Visual
Number of Pump Seals	30	30
Monitoring Time, Man-Min/Source	x 10	x .5
Monitoring Time Per Interval, Min	300	15
Number of Times Monitored Annually[a,b]	x 12/60	x 52/60
Monitoring Time Total, Man-hours	60	13
Repairs		
Number of Pump Seals	30	
Fraction of Leaks Found Annually[a]	x 0.408	
Estimated Number of Repairs Annually	12.2	
Labor Hours Per Repair	x 16	
Repair Times Total, Man-Hours	195	
Estimated Number of Repairs Annually	11.8	
Seal Costs, $/Single Seal	x 164	
Annual Materials Cost	1,935	
Aggregation of Costs		
Instrument Monitoring Hours	60	
Visual Monitoring Hours	13	
Repair Hours	+ 195	
Total Labor Hours	268	
Labor Charge Rate, $/Man-Hour	x 21	
Labor Charges	5,628	
Admin. & Support Costs (0.4 x Labor Charges)	2,251	
Materials Costs	1,935	
Annualized Charges for Initial Repairs	+ 273[c]	
TOTAL ANNUAL COSTS	$10,087	

[a]Fraction of sources repaired annually is an output of the LDAR model.
[b]The number of times monitored annually is divided by "60" to convert from man-minute to man-hours.
[c]From Table 4a.

Table 3b. ANNUAL COSTS OF A LEAK DETECTION AND REPAIR PROGRAM FOR PUMP SEALS--MONTHLY MONITORING: AIR OXIDATION

Monitoring	Instrument	Visual
Number of Pump Seals	27	27
Monitoring Time, Man-Min/Source	x 10	x 0.5
Monitoring Time Per Interval, Min	270	13.5
Number of Times Monitored Annually[a,b]	x12/60	x52/60
Monitoring Time Total, Man-hours	54.0	2.7
Repairs		
Number of Pump Seals	27	
Fraction of Leaks Found Annually[a]	x 0.408	
Estimated Number of Repairs Annually	11.0	
Labor Hours Per Repair	x 16	
Repair Times Total, Man-Hours	176	
Estimated Number of Repair Annually	11.0	
Seal Costs, $/Single Seal	x 164	
Annual Materials Cost	1,804	
Aggregation of Costs		
Instrument Monitoring Hours	54.0	
Visual Monitoring Hours	2.7	
Repair Hours	+ 176	
Total Labor Hours	232.7	
Labor Charge Rate, $/Man-Hour	x 21	
Labor Charges	$4,887	
Admin. & Support Costs (0.4 x Labor Charges)	1,955	
Materials Costs	1,804	
Annualized Charges for Initial Repairs	+ 248[c]	
TOTAL ANNUAL COSTS	$8,894	

[a]Fraction of sources repaired annually is an output of the LDAR model.
[b]The number of times monitored annually is divided by "60" to convert from man-minute to man-hours.
[c]From Table 4b.

Table 4a. COSTS OF INITIAL LEAK DETECTION AND REPAIR OF PUMP SEALS
ETYLENE OXIDE MODEL UNIT : OXYGEN-OXIDATION

Number of Pump Seals	30
Initial Leak Frequency	x 0.088
Estimated Number of Leaks	2.64
Repair time, man-hour/leak	x 16
Labor hours required	42.2
Labor charge rate, $/man-hour	x 21
Initial leak repair	886
Admin. & Support Costs (0.4 x Initial leak repair)	+ 354
SUBTOTAL	1,240
Seal costs, $/single seal[a]	164
Estimated Number of Leaks	2.64
Materials Cost	433
Subtotal (from above)	1,240
TOTAL CAPITAL COSTS	1,673
Capital recovery factor[b]	x .163
ANNUALIZED COST OF CAPITAL	$ 273

[a]Fraction of sources repaired annually is an output of the LDAR model.
[b]The number of times monitored annually is divided by "60" to convert from man-minutes to man-hours.

TABLE 4b. COSTS OF INITIAL LEAK DETECTION AND REPAIR OF PUMP SEALS
ETHYLENE OXIDE MODEL UNIT : AIR OXIDATION

Number of Pump Seals	27
Initial Leak Frequency	x 0.088
Estimated Number of Leaks	2.4
Repair Time/Man-Hour/Leak	x 16
Labor Hours Required	38.4
Labor Charge Rate, $/Man-Hour	x 21
Initial Leak Repair	806
Admin. & Support Costs (0.4 x Initial Leak Repair)	+ 323
Sub-Total (Labor Charges)	1,129
Seal Costs, $/Single Seal[a]	164
Estimated Number of Leaks	x 2.4
Materials Cost	394
Subtotal (from above)	1,129
TOTAL CAPITAL COSTS	$1,523
Capital Recovery Factor[b]	x 0.163
ANNUALIZED COST OF CAPITAL	248

[a]Cost of single seal (replacement) includes a 50 percent credit for the old seal.

[b]Capital recovery factor is based on a 10 percent interest rate over a 120-year period.

Table 5a. ANNUAL COSTS OF A LEAK DETECTION AND REPAIR PROGRAM
VALVES--MONTHLY MONITORING: OXYGEN-OXIDATION

	Instrument
Monitoring	
Number of Valves	870
Monitoring Time, Man-Min/Source	x 10
Monitoring Time Per Interval, Min.	8,700
Number of Times Monitored Annually	x 12/60
Monitoring Time Total, Man-hours	1,740
Repairs	
Number of Valves	870
Fraction of Leaks Found Annually[a]	x .191
Estimated Number of Repairs Annually	166
Labor Hours Per Repair[a]	x 1.13
Repair Times Total, Man-Hours	188
Aggregation of Costs	
Instrument Monitoring Hours	1,740
Repair Hours	+ 188
Total Labor Hours	1,928
Labor Charge Rate, $/Man-Hour	21
Labor Charges	40,488
Admin. & Support Costs (0.4 x Labor Charges)	16,195
Annualized Charges for Initial Repairs	+ 352[b]
TOTAL ANNUAL COSTS	57,035

[a]"Fugitive Emission Sources of Organic Compounds--Additional Information on Emissions, Emission Reductions, and Costs," EPA-450/3-82-010, P.5-8.
% Leaks=(#Leaks/yr)/(#Valves)
[b]From Table 6a.

Table 5b. ANNUAL COSTS OF A LEAK DETECTION AND REPAIR PROGRAM
VALVES--MONTHLY MONITORING: AIR-OXIDATION

	Instrument
Monitoring	
Number of Valves	781
Monitoring Time, Man-Min/Source	x 10
Monitoring Time Per Interval, Min.	7,810
Number of Times Monitored Annually	x 12/60
Monitoring Time Total, Man-hours	1,562
Repairs	
Number of Valves	781
Fraction of Leaks Found Annually[a]	x .191
Estimated Number of Repairs Annually	149
Labor Hours Per Repair[a]	x 1.13
Repair Times Total, Man-Hours	168
Aggregation of Costs	
Instrument Monitoring Hours	1,562
Repair Hours	+ 168
Total Labor Hours	1,730
Labor Charge Rate, $/Man-Hour	x 21
Labor Charges	36,330
Admin. & Support Costs (0.4 x Labor Charges)	14,532
Annualized Charges for Initial Repairs	+ 331[b]
TOTAL ANNUAL COSTS	51,193

[a]"Fugitive Emission Sources of Organic Compounds--Additional Information on Emissions, Emission Reductions, and Costs," EPA-450/3-82-010, P.5-8.
% Leaks=(#Leaks/yr)/(#Valves)
[b]From Table 6b.

Table 6a. COSTS OF INITIAL LEAK DETECTION AND REPAIR OF VALVES
ETHYLENE OXIDE PRODUCTION: OXYGEN OXIDATION

	Service	
	Gas	Light Liquid
Number of Valves	177	693
Initial Leak Frequency[a]	x 0.114	x 0.065
Estimated Number of Leaks	20	45
Repair Time, Man-Hour/Leak[a]	x 1.13	x 1.13
Labor Hours Requires	22.6	51
Labor Charge Rate, $/Man-Hour	x 21	x 21
Initial Leak Repair	475	1,071
Admin. & Support Costs (0.4 x Initial Leak Repair)	+ 190	+ 428
	665	1,499
Total Capital Costs	665	1,499
Capital Recovery Factor[b]	x 0.163	x 0.163
Annualized Cost of Capital	108	244

[a]"Fugitive Emission Sources of Organic Compounds--Additional Information on Emissions, Emission Reductions, and Costs," EPA-450/3-82-010, p. 5-7.

[b]Capital Recovery Factor is based on a 10 percent interest rate over a 10-year period.

Table 6b. COSTS OF INITIAL LEAK DETECTION AND REPAIR OF VALVES
ETHYLENE OXIDE PRODUCTION: AIR OXIDATION

	Service	
	Gas	Light Liquid
Number of Valves	200	58.1
Initial Leak Frequency[a]	x 0.114	x 0.065
Estimated Number of Leaks	23	38
Repair Time, Man-Hour/Leak[a]	x 1.13	x 1.13
Labor Hours Requires	26	43
Labor Charge Rate, $/Man-Hour	x 21	x 21
Initial Leak Repair	546	903
Admin. & Support Costs (0.4 x Initial Leak Repair)	+218	+ 361
	764	1,264
Total Capital Costs	764	1,264
Capital Recovery Factor[b]	x 0.163	x 0.163
Annualized Cost of Capital	125	206

[a]"Fugitive Emission Sources of Organic Compounds--Additional Information on Emissions, Emission Reductions, and Costs," EPA-450/3-82-010, p. 5-7.

[b]Capital Recovery Factor is based on a 10 percent interest rate over a 10-year period.

Table 7a.

COSTS OF EQUIPMENT CONTROL IN MODEL UNIT (OCT 1983$)
Ethylene Oxide Production Plants
(Oxygen Oxidation Process)

Source	Number Of Components	Component Captial Cost, $ Source	Capital Cost, $	Component Annualized Cost $/Source	Annualized Cost, $
Safety/Relief Valves (G)[a]	7[b]	3,765[e]	26,355	1,120[e]	7,840
Open-Ended Lines	0[c]	65[e]	0	16[e]	0
Compressors	3	9,470[e]	28,410	2,400[e]	7,200
Sampling Connections	10[d]	670[e]	6,700	170[e]	1,700
TOTAL			61,465		16,700

[a]Component control costs are comprised of 50 percent RD/block valve and 50 percent RD/3-way valve.

[b]75 percent of gas service safety/relief valves are assumed to be controlled at baseline; therefore, the emissions reduction and costs of control are based on 7 valves instead of 26.

[c]All open-ended lines (in model unit) are assumed to be controlled at baseline; therefore, there are no associated costs of control or emissions reduction.

[d]75 percent of sampling connections are assumed to be controlled at baseline; therefore, the emissions reduction and costs of control are based on 10 out of 40 sampling connections.

[e]From Table 8.

TABLE 7b.

COSTS OF EQUIPMENT CONTROL IN MODEL UNIT (OCT 1983$)
Ethylene Oxide Production Plants
(Air Oxidation Process)

Source	Number Of Components	Component Capital Cost, $ Source	Capital Cost, $	Component Annualized Cost $/Source	Annualized Cost, $
Safety/Relief Valves (G)[a]	15[b]	3,765[e]	56,475	1,120[e]	16,800
Open-Ended Lines	0[c]	65[e]	0	16[e]	0
Compressors	6	9,470[e]	56,820	2,400[e]	14,400
Sampling Connections	36[d]	670[e]	24,120	170[e]	6,120
TOTAL			137,415		37,320

[a]Component control costs are comprised of 50 percent RD/block valve and 50 percent RD/3-way valve.

[b]75 percent of gas service safety/relief valves are assumed to be controlled at baseline; therefore, the emissions reduction and costs of control are based on 15 valves instead of 60.

[c]All open-ended lines (192 in model unit) are assumed to be controlled at baseline; therefore, there are no associated costs of control or emissions reduction.

[d]75 percent of sampling connections are assumed to be controlled at baseline; therefore, the emissions reduction and costs of control are based on 36 out of 145 sampling connections.

[e]From Table 8.

TABLE 8 COSTS OF CONTROLLING FUGITIVE VOC EMISSIONS USING EQUIPMENT CONTROLS (Oct 83$)

Source	Control Technique	Capital Cost, $/Source	Amortization Period, Years	Capital Recovery Factor[a]	Factor for Other Capital Charges[b]	Annualized Cost, $/Source
Pump (LL)	Seal system/flare	4,690[e]	2/10[c]	0.58/0.163[c]	0.09	1,650
	Seal system/enclosed device	8,400[e]	2/10[c]	0.58/0 163[c]	0.09	2,590[e]
Safety/Relief Valves (G)	RD/block valves	2,510[f]	2/10[d]	0.58/0 163[d]	0.09	750[f]
	RD/3-way valve	5,020[f]	2/10[d]	0.58/0 163[d]	0.09	1,490[f]
	Soft-seals (O-rings)	2909	10	0.163	0.09	73
	Connection to flare	2,8409	10	0.163	0.09	720
Open-ended Lines	2nd valve	659	10	0.163	0.09	16
Compressors	Seal system	94709	10	0.163	0.09	2,400
Sampling Connections	Closed purge system	6709	10	0.163	0.09	170

[a]Capital recovery factor (CRF) is computed using the 10 percent interest rate (i) and the amortization period (n):

$$CRF = \frac{i\ (1 + i)^n}{(1 + i)^n - 1}$$

[b]Other capital charges include maintenance, taxes, insurance, etc.; 9 percent of the capital cost is used for those charges.

[c]A 2-year period is used for the seal; a 10-year period is used for piping and installation charges.

[d]A 2-year period is used for the disk; a 10-year period is used for piping and installation charges.

[e]From Table 9

[f]From Table 10.

[g]Apply CE plant cost index ration (Oct 1983/1978) 318.2/218.8 = 1 45 to figures in Table 2 of Memo: Subject: Procedure to Compile Control Cost, From: John Stelling, To: SOCMI Fugitive NSPS File, March 11, 1983

Table 9. EQUIPMENT COST FOR CONTROL OF EMISSIONS FROM A PUMP SEAL
(October 1983 dollars)

	Degassing Reservoir Vented to a Flare	Degrassing Reservior Vented to an Enclosed Combustion Device
Capital Costs		
Dual seal[a]	1490[h]	1490[h]
Barrier fluid[b]	2180	2180
Vent system	1015[c]	4730
Total	4685	8400
Annual Costs		
Dual seal[d]	707	707
Barrier fluid[e]	355	355
Vent system[e]	165	770
Maintenance & Miscellaneous charges[f]	421	756
Total[g]	1648	2588

[a]Based on $1250/seal (1980 dollars) average cost quoted by industry. 1978 cost = $1030 (seal cost = $1015, installation cost = $240, single seal credit = $225). See Table 10 for 1983 dollars.

[b]From Chapter 8 of the BID.

[c]Based on installed capital cost of 20m of 5.1cm piping ($850), one 5.1cm check valve ($125), and one 5.1cm block valve ($415) per vent system and one vent per pair of pump seals (1978 Dollars).

[d]Based on 2 year seal life and 10 percent interest (CRF = 0.58) for dual seal and 10 year amortization period and 10 percent interest (CRF = 0.163) for installatin charges.

[e]Based on 10 year equipment life and 10 percent interest (CRF = 0.163).

[f]Based on 9 percent of total capital costs (Chapter 8 of the BID).

[g]Costs do not include credits for recovered product.

TABLE 10. RELIEF VALVE CONTROL COSTS
(October 1983 $)

(1) Rupture disk systems with block valves — Total Capital Cost = $2,509 relief valve

	Annualized Costs	Capital Costs
Rupture disk	$166	$ 283
Holders, etc.	363	2,226
Maintenance & Misc.	226	
TOTAL ($/year)	$754	$2,509

(2) Rupture disk systems with 3-way valve

Assembly

One 7.6 cm stainless steel rupture disk		$ 282
One 7.6 cm carbon steel disk holder		471
One 0.6 cm dial face pressure gauge		22
One 7.6 cm safety/relief valve		1,800
Two 7.5 cm elbows		36
	SUBTOTAL	$2,612

Three-way Valve

One 7.6 cm, 3-way, 2 port valve		$1,624
Installation		783
	SUBTOTAL	$2,407

TOTAL COST $5,019

	Annualized Costs
Rupture disk	$ 154
Holder, valve, etc.	772
Maintenance & Misc.	552
TOTAL ($/year)	$1,478

APPENDIX B

Dispersion Modeling Parameters

HUMAN EXPOSURE MODEL

EPA's Human Exposure Model (hEM) is a general model capable of producing quantitative expressions of public exposure to ambient air concentrations of pollutants emitted from stationary sources. The input data needed to operate this model include source data that are typically required for the operation of dispersion models (e.g. plant location, height of emission release point, and velocity of stackgases). Based on the source data, the model estimates the magnitude and distribution of ambient air concentrations of the pollutant in the vicinity of each source.

The dispersion model used is a Gaussian diffusion model that uses the same basic dispersion algorithm as EPA's Climatological Dispersion Model (CDM), but has been simplified to improve overall efficiency. In general, CDM determines long-term (seasonal or annual) quasi-stable pollutant concentrations at any ground level receptor using average emission rates from point and area sources and joint frequency distribution of wind direction, wind speed, and stability for the same period.

Stability array (STAR) summaries are the principal meteorological input to the HEM dispersion model. STAR data are standard climatological frequency-of-occurrence summaries formulated for use in EPA models and available for major U.S. meteorological monitoring sites from the National Climatic Center. A STAR summary provides a frequency-of-occurrence of wind speed, stmospheric stability, and wind direction, classified according to Pasquill's categories.

Estimates of human exposure are developed using dispersion modeling of emissions that pairs population density estimates with predicted pollutant concentrations from the concentration grid described above. Estimates of

the number and distribution of people residing within 50 km of each plant are based on a slightly modified version of the Census Bureau's "Master Enumeration District List--Extended" (MED-X) data base.

Dispersion results for ethylene oxide production facilities are presented below:

DISPERSION RESULTS

Production Plants	Maximum Annual Average Concentration (ppm)	Maximum Annual Average Concentration ($\mu g/m^3$)
1	0.002	3.59
2	0.002	3.05
3	0.0006	0.98
4	0.004	6.37
5	0.004	6.30
6	0.001	2.29
7	0.0001	0.22
8	0.001	2.15
9	0.003	4.92
10	0.011	18.8
11	0.004	7.54
12	0.002	2.96
13	0	0
14	0.0002	0.29
15	0.005	9.12

TABLE 1.

Dispersion Modeling Parameters
Ethylene Oxide/Production Facilities

Plant/Emission Source	North Latitude (deg/min/s)	West Longitude (deg/min/s)	Urban 0 Rural 1	Emission Rate (kg/yr)	Stack/Vent Height (meters)	Source Area (m^2)	Stack(0) Vent(1)	Stack/Vent Diameter (meters)	Emis. Velocity (m/s)	Emis. Temp. (K)
1 Process	30 11 22	90 59 43		7,400	25.4	--	1	0.23	17	346
Cooling Tower				15,300	16	--	1	5.98	11.7	314
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
2 Process	29 37 24	95 03 34		6,600	25.4	--	1	0.23	17	346
Cooling Tower				13,500	16	--	1	5.98	11.7	314
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
3 Process	28 59 34	95 24 22		4,600	25.4	--	1	0.23	17	346
Cooling Tower				--	--	--	-	--	--	--
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
4 Process	30 19 00	91 16 20		34,800	25.4	--	1	0.23	17	346
Cooling Tower				--	--	--	-	--	--	--
Equipment Leaks				113,000	--	20,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
5 Process	29 37 44	95 03 04		7,700	25.4	--	1	0.23	17	346
Cooling Process				15,900	16	--	1	5.98	11.7	314
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--

TABLE 1. (cont'd)

Dispersion Modeling Parameters
Ethylene Oxide/Production Facilities

Plant/Emission Source	North Latitude (deg/min/s)	West Longitude (deg/min/s)	Urban 0 Rural 1	Emission Rate (kg/yr)	Stack/vent height (meters)	Source Area (m^2)	Stack(0) Vent(1)	Stack/Vent diameter (meters)	Emis. Velocity (m/s)	Emis. Temp. (K)
6 Process	41 24 30			3,600	25.4	--	1	0.23	17	346
Cooling Tower				7,300	16	--	1	5.98	11.7	314
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
7 Process	38 00 10	86 07 16		1,700	25.4	--	1	0.23	17	346
Cooling Tower				3,500	16	--	1	5.98	11.7	314
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
8 Process	30 3 38	94 2 53		2,600	25.4	--	1	0.23	17	346
Cooling Tower				5,400	16	--	1	5.98	11.7	314
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
9 Process	30 11 12	90 59 28		10,800	25.4	--	1	0.23	17	346
Cooling Tower				22,300	16	--	1	5.98	11.7	314
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
10 Process	39 48 20	75 25 40		1,700	25.4	--	1	0.23	17	346
Cooling Tower				110,000	16.8	--	1	7.3	40	283
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--

TABLE 1. (cont'd)

Dispersion Modeling Parameters
Ethylene Oxide/Production Facilities

Plant/Emission Source	North Latitude (deg/min/s)	West Longitude (deg/min/s)	Urban 0 Rural 1	Emission Rate (kg/yr)	Stack/vent Height (meters)	Source Area (m^2)	Stack(0) Vent(1)	Stack/Vent diameter (meters)	Emis. Velo-city (m/s)	Emis. Temp. (K)
11 Process				5,400	25.4	--	1	0.23	17	346
Cooling Tower				--	--	--	-	--	--	--
Equipment Leaks				113,000	--	20,000	-	--	0.01	273
Effluent				1,100	--		-	--	0.01	273
12 Process	32 26 44	94 41 17		3,000	25.4	--	1	0.23	17	346
Cooling Tower				6,200	16.8	--	1	7.3	40	283
Equipment Leaks				61,500	--	76,000	-	--	0.01	273
Effluent				0	--	--	-	--	--	--
13 Process	17 59 36	66 44 46		5,000	25.4	--	1	0.23	17	346
Cooling Tower				--	--	--	-	--	--	--
Equipment Leaks				113,000	--	20,000	-	--	0.01	273
Effluent				1,000	--		-	--	0.01	273
14 Process	28 30 30	96 46 15		7,100	25.4	--	1	0.23	17	346
Cooling Tower				--	--	--	-	--	--	--
Equipment Leaks				113,000	--	20,000	-	--	0.01	273
Effluent				1,500	--		-	--	0.01	273
15 Process	29 59 27	90 26 50		10,000	25.4	--	1	0.23	17	346
Cooling Tower				--	--	--	-	--	--	--
Equipment Leaks				113,000	--	20,000	-	--	0.01	273
Effluent				2,000	--	--	-	--	0.01	273

TABLE 2.

DISPERSION MODELING PARAMETERS[a]
Ethylene Oxide/Ethoxylator, Sterilizer, and Fumigator Facilities

Model Plant/Emission Source		Emission Rate (Kg/yr)	Stack/vent Height (meters)	Source Area (m^2)	Stack (0) Vent(1)	Stack/vent Diameter (meters)	Emission Velocity (m/s)	Emission Temp. (k)
Ethoxylators/Equipment Leaks		6,100	--	20,000	--	--	0.01	273
Sterilizers/Vent Emissions and Fumigators	1[c] (Low)	7,000	25.4	--	1	0.23	17	273
	2[d] (High)	30,000	25.4	--	1	0.23	17	273

[a]All parameters are assumed.

[b]10% of 61.5 Mg/yr

[c]Assumes 450 facilities.

[d]Assumes 100 facilities.

Table 3. Ethylene Oxide Plant Production Capacity

Plant Number	Plant	Location	Capacity (10^3kg EO)
1	BSAF	Geismar, LA	218,000
2	Celanese	Clear Lake, TX	193,000
3	Dow	Freeport, TX	136,000
4	Dow	Plaquemine, LA	205,000
5	ICI Americas	Bayport, TX	227,000
6	Northern Petrochemical	Morris, IL	105,000
7	Olin	Brandenburg, KY	50,000
8	PPG	Beaumont, TX	77,000
9	Shell	Geismar, LA	318,000
10	Sun Olin	Claymont, DA	50,000
11	Texaco	Port Noches, TX	318,000
12	Texas Eastman	Longview, TX	87,000
13	Union Carbide	Ponce, P. R.	295,000
14	Union Carbide	Seadrift, TX	418,000
15	Union Carbide	Taft, LA	590,000

Table 4. Model Plant Dispersion Parameters

Source	Emission Factor ($kg/10^3$ kg capacity)		Ht./D (m)	Vel. (m/sec)	Temp. (K)
	Air	O_2			
Process Vent(s)	0.017	.034	25.4/ .23	17	346
Cooling Tower	N/A	.07	16 /5.96	11.7	314
Effluents	.0035	.0	N/A	0.01	273
	(Mg/yr)				
Equipment Leaks	113	61.5	N/A	0.01	273